SIEMENS

Demand Control Ventilation Application Guide for Consulting Engineers

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TO THE READER

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About this Application Guide

This section discusses:

- The Goal of this Guide
- How this Guide is Organized
- It also provides information on conventions and symbols used, how to access help, and where to direct comments about this application guide.

Goal of this Guide

The goal for this application guide is to give the reader the benefit of the company's significant experience in Demand Control Ventilation (DCV) projects. Information and guidance here is based on those past success and challenges. It is assumed that the reader is familiar with building automation products and systems from Siemens Industry, Inc.

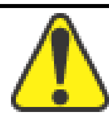
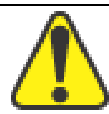
How this Guide is Organized

This application guide contains the following chapters:

- *Chapter 1 - Introduction to IAQ and Ventilation Control*, presents background information on Indoor Air Quality and ventilation control that applies to many ventilation control systems.
- *Chapter 2 - Concept and Sequence of Operation*, includes information specific to the ventilation control application presented in this guide. It tells how the application works and why it works that way.
- *Chapter 3 - Designing a Central DCV System*, describes the tasks carried out by the control design engineer applying this system.
- *Chapter 4 - Implementing, Troubleshooting and Maintaining a Central DCV System*, describes tasks likely to be carried out on the job site as the system is started up.
- *Appendix A* - Series 2200 Three-in-one Room Unit Technical Data and Features
- The *Glossary* describes the terms and acronyms used in this guide.
- The *Index* helps you locate information presented in this guide.

Symbols

The following table lists the symbols that may be used in this application guide to draw your attention to important information.

Notation	Symbol	Meaning
WARNING:		Indicates that personal injury or loss of life may occur to the user if a procedure is not performed as specified.
CAUTION:		Indicates that equipment damage, or loss of data may occur if the user does not follow a procedure as specified.
Note		Provides additional information or helpful hints that need to be brought to the reader's attention.
Tip		Suggests alternative methods or shortcuts that may not be obvious, but can help the user better understand the capabilities of the product, service, or solution.

Getting Help

For more information about Demand Control Ventilation (DVC), contact your local Siemens Representative.

Where to Send Comments

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Chapter 1 – Introduction to IAQ and Ventilation Control

Chapter 1 presents background information that applies to many ventilation control systems, not just to the application covered in this guide. It includes information on the following topics:

- Background on IAQ and ventilation control
- Ventilation rates and requirements
- DCV opportunities
- Central DCV vs. Zone-level DCV
- Use of a purge cycle
- Methods of controlling building pressure
- Controlling outside air intake

Background Information and Resources

IAQ inside buildings is the result of a combination of many variables. Some include:

- Materials used in construction
- Contaminants that exist in the local ambient air
- Gases effused from the ground the building is built on
- Chemicals and equipment that are brought into the building
- Filtering methods
- Human off gassing
- Ventilation effectiveness

All of these factors, and more, are taken into consideration when designing a building.

After the building is in operation, proper management draws on a broad range of disciplines to maintain adequate IAQ. Most of the IAQ is managed by the maintenance and operations of the building. Methods to manage good IAQ include:

- Storing and using cleaning agents correctly
- Handling and removing trash effectively
- Maintaining ventilation filters
- Seeking out and mitigating sources of long term moisture
- Operating a ventilation system according to design

Sometimes users can have a positive or negative impact on IAQ. For instance, workers who maintain an organized desk that can be cleaned by cleaning crews will have a better IAQ than workers who stack boxes and files that are allowed to collect dust.

There are many useful resources that cover IAQ more broadly. These resources discuss, among other issues, the sources of air contaminants and how to control them. They provide guidance for questions like the following:

- How are cleaning chemicals stored?
- Where does the garbage sit before it is taken out?
- Are the air intakes clean?

Some of these documents, and tools that IAQ designers can use to improve IAQ, can be obtained from the U.S. Environmental Protection Agency. Here are some Web sites from the U.S. EPA that may be useful at the time of this writing:

- For green buildings: http://www.epa.gov/greenbuilding/index.htm
- For large buildings: http://www.epa.gov/iaq/largebldgs/index.html
- IAQ design tools for schools: http://www.epa.gov/iaq/schooldesign/
- IAQ tools for schools: http://www.epa.gov/iaq/schools/index.html
- Molds and moisture: http://www.epa.gov/mold/index.html
- Second-hand smoke and going smoke-free: http://www.epa.gov/smokefree/

Another good source of information is ASHRAE Standard 62.1: Ventilation for Acceptable Indoor Air Quality, which describes the ventilation requirements related to IAQ. However, it does not address other aspects of IAQ or ventilation. Use this, along with applicable building codes and the customer's own standards, to determine ventilation requirements.

IEQ versus IAQ

The terms indoor environmental quality (IEQ) and indoor air quality (IAQ) are often mistakenly interchanged. The differences are subtle, but worth understanding. *IEQ* refers to the overall environment and all parameters that affect the occupants, such as temperature, humidity, lighting, noise, controllability, safety and others. IEQ includes IAQ.

IAQ is more specifically defined as "a function of the interaction of contaminant sources and the effectiveness of ventilation utilized to dilute and remove air contaminants" (Bearg 2008). It is physically impossible to eliminate all sources of air contaminants. Even outdoors, a considerable amount of air contaminants exist. The process to manage IAQ inside buildings is first to minimize the sources, then exhaust known unavoidable sources, then dilute the rest of the air to mitigate build up of contaminants[1].

This document focuses on the dilution part of the building IAQ process. In ASHRAE 62.1-2010, it is referred to as Ventilation requirements and a method called Demand Control Ventilation.

[1] Measuring IAQ Parameters *HPAC Engineering*, Aug 1, 2008 12:00 PM, By DAVID W. BEARG, PE, CIH Life Energy Associates Concord, Mass.

Role of Ventilation in IAQ

Ventilation is one part of the overall process to maintain IAQ in a commercial or institutional building. In a building, contaminants build up over time. Some contaminants come from outside, some come from inside and some come from the occupants. The primary goal of ventilation is to reduce airborne contaminants by diluting indoor air, which has a higher concentration of contaminants, with outdoor air that has less contaminant.

Role of Exhaust Air in Ventilation

The first parameter that a design engineer evaluates is how much exhaust is needed for the special spaces that cause low IAQ. These are the spaces that are needed for a normal operation of a building and cannot be avoided. As long as they are well defined and designed, they can be handled in an efficient way. Some of the spaces in commercial buildings that require special exhaust handling include:

- Trash rooms
- Kitchen or pantry exhaust
- Copy room exhaust
- Bathroom exhaust

Other spaces often have special exhaust systems that may be there to handle high temperature loads, and not necessarily IAQ, for instance:

- Computer rooms
- Electrical closets

Some buildings by design have special exhaust or ventilation needs above and beyond the typical commercial building design, such as:

- Labs
- Healthcare facilities
- Pools and pool water treatment rooms
- Indoor garages

Special standards and codes are written for these types of environments and an experienced consultant should be retained for designing systems for these facilities.

Interior Design Component of Ventilation

Some contaminants are from the building. Many materials used in construction give off gasses that negatively impact the health and comfort of occupants. These gasses are called effluents. More specifically, they are referred to as Volatile Organic Compounds (VOC). Materials that give off measurable amounts of VOCs include:

- Paint
- Carpet
- Hard floorings and varnish
- Sealants

- Plastics in furniture
- Computers
- Plants

These materials emit a high level of VOCs when they are new. That is why it is often noticeable when a building is newly constructed, renovated or even painted. These materials continuously emit VOCs. Over time, the rate of emitting VOCs in most materials decline with age. The rate of emitting VOCs drops dramatically over the first few weeks of use or installation. Then over the first few years, the emitting rate continues to drop to a lower level. Eventually, it drops to a consistent rate. That is why guidelines are written to purge new construction buildings in order to eliminate the highest concentration of VOCs and some guidelines call for increasing ventilation for a year or two.

Many of these materials are now becoming available in low-emitting versions. Even so, the design engineer must design an amount of ventilation to dilute the anticipated VOC levels. Most jurisdictions and professionals reference ASHRAE Standard 62.1 to determine the amount of ventilation needed for dilution of the Interior Design Component.

In the ASHRAE 62.1 standard, table 6-1 defines a factor called “Area Outdoor Air Rate (R_a)”. There are a variety of values that correspond to different types of spaces. The values guide the engineer to a ventilation rate per square foot of space. The design engineer can also, at his discretion, add design factors for special cases, such as high concentration of painted walls, high concentration of computers, or high concentration of art materials such as architects or designers offices. <u>The design engineer cumulates the ventilation rates for all of the spaces to determine a ventilation rate for the area.</u>

Role of Population in Ventilation

Humans are another source of contaminants. Ventilation is intended to dilute odorous bioeffluents from occupants and other sensory contaminants that result directly from occupant activities. It is proportional to the number of people expected to occupy the space. These include:

- Metabolic odors
- Odors from clothes, shoes and coats
- Odors from lotions, perfumes and hair products
- Food odors
- Machines that humans use, such as copiers and printers

Up until 1999, the guidelines for ventilation were to predict the normal population of a building. More specifically, the design engineer anticipated the normal or maximum population of each space and added them up. This often resulted in highly ventilated spaces. This was not a problem for IAQ, but the cost of the ventilation was higher than it needed to be.

In 1999, an updated version of ASHRAE 62.1 was issued that allowed for changing ventilation base on predictable or sensed changes in population. Thus, the ventilation rate could change based on the demand. This is the establishment of Demand Control Ventilation. Further refinements to DCV methods were issued in 2001, 2004, 2007 and 2010.

Role of Outside Air in Ventilation

Fresh air from outside the building is the media used to dilute contaminants inside buildings. The whole process of diluting contaminants is ventilation. Outside air intake flow is one important component of ventilation, but it includes much more.

Ventilation includes the entire process of air delivery and air removal for a space. This process includes outside air intake, mixing, delivery through the duct system, the air terminals, and diffusion through the space. Ventilation also includes the mixing processes in the space, and the entire exhaust process. A system has to function correctly all the way through the process to effectively ventilate a space. While outside air intake is one of the many challenging and crucial steps in this process, it is not the whole process of ventilation.

"Outdoor Air" and "Ventilation Air"

The terms outdoor air and ventilation air are often used interchangeably. There is an important distinction between them. *Outdoor air*—also called intake air, fresh air or first pass air—describes air brought into the building from the outdoors. *Ventilation air* is typically a mixture of outdoor and recirculated air used to dilute contaminants within a building's occupied spaces.

Role of Control in Ventilation

Proper control function is another necessary aspect of ventilation. The control system coordinates all of the moving parts that must work together to achieve the intended ventilation. Controls sense conditions, move dampers, speed fans up and down and switch between operating modes. Control includes setting the right mix of outside air in the supply air, balancing the flows in and out of the building, and supplying the right flow rate to each zone. If all of these controls operate correctly, it is possible to achieve proper ventilation.

However, proper control cannot overcome a ventilation system that is inadequate in other ways. Control functions do not compensate for poor air diffusion, inappropriate contaminant sources in the space, mold in the ventilation equipment, or outside air intakes that draw contaminated air.

Determining Ventilation Volume

The volume of ventilation that must be designed for a building is codified. It is up to the Professional Engineer to design for the amount needed to meet codes and other guidelines. Previously, the document names several resources that are referred to for special applications. For Ventilation, the most common reference is ASHRAE 62.1 – Ventilation for Acceptable Indoor Air Quality.

Since 2004, ASHRAE has prescribed a two-step calculation for determining the amount of ventilation needed for a common building space. One step is square footage of building space and second step is human population. These two components added together result in the amount of dilution air that must be delivered to the occupied spaces.

If exhaust air for special applications exceeds the amount of outside air intake normally needed for ventilation, or if there is a great amount of exhaust air needed for one area of a building, then the ventilation system must be designed to replace that air, in addition to the diluted air needed for the occupied spaces.

Relationship between Population and Ventilation

Human bioeffluents is one of the contaminants that must be diluted in order to maintain a comfortable and healthy indoor environment. Bioeffluents increase with the density of the occupancy. Bioeffluents also increase in proportion to the activity of the occupants. The ventilation system must be sized to handle the worst expected case of bioeffluent build up. It is based upon the full design occupancy of the building and the expected activities of all occupants. Often, additional ventilation is designed to account for spaces where occupants in a building gather in high density for temporary activities, such as conference rooms, cafeterias, exercise rooms, classrooms, etc. This sizing activity determines the design ventilation amount for the building.

Relationship between CO_2 and Ventilation

Humans are a source of contamination of air inside buildings. Humans and the activities they perform lead to odors that can be sensed by others. When 80% of the occupants perceive the air to be free from annoying odors, then the air is generally deemed acceptable. Diluting the human component of contamination is important for IAQ. Typically, the engineer anticipates a design population and sizes the ventilation system to always dilute for that amount of people. A more energy efficient way to ventilate would be to measure the amount of people who occupy a space on a real-time basis and only ventilate for that measured or calculated amount. This is called *Demand Control Ventilation (DCV)*.

In order to ventilate for human contamination via DCV, engineers must be able to predict, calculate or measure the population changes in the building over time, and understand where that population occupies. Humans exhaust CO2 at predictable, but varying, rates depending on the activity they are performing. The increase in levels of CO2 inside a building is correlated to the population inside the building, assuming there is not another source of CO2.

CO2 is a convenient and easy gas to measure. It exists naturally in ambient air. Relatively inexpensive sensors can measure the CO2 level in the air. CO2 sensing is a convenient indicator of the relative amount of people that occupy a zone inside a building. As the increase population is sensed, the ventilation requirements go up.

When considering the relationship between CO_2 and ventilation, the most important point to understand is that CO_2 is not considered an air contaminant at the concentrations commonly found in most buildings (400 – 3000 ppm). There are no health implications of CO_2 in concentrations below several thousand parts per million (ppm). However, in concentrations at or just below about 3000 ppm, people start to feel tired and listless, many complain of "stuffiness" or being "warm" in the room, and they have trouble concentrating. The Occupational Safety and Health Administration(OSHA) lists 5000 ppm as the threshold limit value for a time-weighted average over five 8-hour workdays and the American Conference of Governmental Industrial Hygienists lists 30,000 ppm as the 15-minute exposure limit. There is also no evidence that CO_2 causes discomfort or dissatisfaction at the levels found in most buildings.

When implementing a Demand Controlled Ventilation (DCV) system based on CO_2 sensing, CO_2 control is a method, not a goal. The goal is to dilute the bioeffluents from the human population. Research has shown that there is a corresponding relationship between the rate that bioeffluents are emitted and CO_2 is exhaled. Because of this relationship, CO_2 can be used as a tracer gas to determine the rate of bioeffluent accumulation. If the increase in CO_2 above normal can be measured, then CO_2 can be used as a means to determine when diluted air needs to be increased or decreased.

The CO_2 concentration is directly related to the amount of other human contaminants that need to be diluted. Therefore, CO2 concentration correlates to ventilation per person, which is proportional to the bioeffluent IAQ parameter. To understand how CO_2 relates to ventilation, consider where the gas comes from, and where it goes in the indoor air.

1. Human respiration is the primary source of CO_2 in most indoor spaces. With every breath, people add a CO_2 to the mix of gasses in the air. The rate at which people generate CO_2 depends on how many people are there, what they are doing, and other physiological factors.
2. Ventilation is the primary mechanism for removing CO_2 from most indoor spaces. The CO_2 sources in an enclosed space add to the concentration inside, so it rises above the concentration outside. A ventilation process that brings in outside air (low CO_2 concentration) and removes room air (high CO_2 concentration) removes CO_2 and other human contaminants from the ventilated space. The removal rate depends on the mix of outdoor air and recirculated air in the ventilation air, the CO_2 generation rate within the space, and the difference in CO_2 concentration between inside and out.
3. The generation and removal of CO_2 proceed at their own rates, dynamically increasing or decreasing the CO_2 concentration in the space. When they balance, the CO_2 concentration reaches a steady value. At this point, it is possible to relate the ventilation rate to the occupancy of the space if you know the difference between the CO_2 concentrations inside and out, and the average rate that the occupants generate CO_2. (See Equation (3) in Chapter 2 under the heading *Determining the Zone Population.)*

The dynamics of the CO_2 concentration reinforces its use as a ventilation indicator. Consider a room at a steady CO_2 concentration. When the activity in the room changes—either more people enter or they become more active—more CO_2 is generated at a higher constant rate. The imbalance between the higher generation rate and the original removal rate adds CO_2 to the room. The concentration increases gradually, and continues to increase until the dilution rate catches up with the generation rate. Eventually, the system stabilizes at a higher CO_2 concentration. This is usually a slow process, similar to a room temperature response. The time to complete the CO_2 change is related to the ventilation air change rate of the room and can range from several hours to about 15 minutes.

The *Indoor Air Quality Guide: Best Practices for Design, Construction and Commissioning* is designed for architects, design engineers, contractors, commissioning agents, and all other professionals concerned with indoor air quality. It is a best practices guide developed jointly by ASHRAE, the American Institute of Architects (AIA), Building Owners and Managers Association (BOMA), Sheet Metal and Air Conditioning Contractors National Association (SMACNA), the U.S. EPA and USGBC. This guide is available for purchase at the following Web address: http://www.ashrae.org/resources--publications/bookstore/indoor-air-quality-guide.

Zone Population Sensing Technologies for DCV Strategies

When most people think of implementing a DCV strategy, they think that CO_2 sensing in the space will automatically be required. However, there are many zone types where CO_2 sensing may not be the best choice. CO_2 sensors are subject to calibration drift and accuracy issues over time; they require proper periodic maintenance (for example, cleaning and re-calibration). If this maintenance is not performed, or not performed in a timely manner, there is some risk involved in keeping the reporting of CO_2 accurate over time. Other technologies exist that can count zone population when implementing a DCV strategy. The benefits of these other methods are simplicity and reliability. The zone population sensing techniques are listed here and described in more detail in the sections below:

- Time-of-day schedules
- Occupancy (on/off) sensors
- People counters
- CO_2 sensors

Time-of-Day Schedules

There are some zone types, such as *school cafeterias* or *university or high school lecture halls*, where a pretty accurate estimate of the daily zone population pattern can be obtained from simply using a time-of-day schedule. For example, in the case of a university lecture hall, it is typically known how many students are registered for a given lecture and the schedule of that lecture (that is, what hours of each day the lecture will be conducted). In this case, ventilation can be supplied to the zone at the level to meet the needs of all the registered students for that lecture at the hours it occurs, then reduced to minimum for other hours, or shut off entirely when unoccupied[2].

Occupancy Sensors

Occupancy sensors that detect whether there are people in the zone or not can also be used for certain zone types as an indicator of the approximate population in that zone. Examples of zones where occupancy sensors can be used to detect population when implementing a DCV strategy are *private offices* and *small conference rooms*. For example, when the occupancy sensor detects a private office is occupied, ventilation can be provided to the zone that is adequate for one person, then reduced to minimum when the occupant leaves the room, or shut off entirely when unoccupied[3]. In the case of a small conference room, when the occupancy sensor detects that there are people in the room, ventilation can be supplied to the conference room at the level to meet the needs of the maximum number of people likely to be meeting, then reduced to minimum for other hours, or shut off entirely when unoccupied[4].

People Counters

Infra-red or light beam sensor technology to count the number of people in a building space or the number of people that pass through a door does exist but, compared to occupancy sensors, are seldom used for implementing a DCV strategy. However, for certain space types, such as *theaters* and *labs*, accurate methods of counting the people occupying a space inside the building do exist. For example, in theaters, the “point of sale” (that is, the number of tickets sold) can be an accurate indicator of the number of people in that zone, and spaces that have card-access systems, such as labs, can also be used to indicate the number of people in that zone.

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[2] We shall see that ASHRAE Standard 62.1-2010 permits shutting off the ventilation to a zone *only* during unoccupied hours when no one is in the zone. During normally occupied hours, if there is no one in the zone, ventilation can be reduced to meet the “floor area” ($R_a \times A_z$) component of the ventilation requirement.

[3] Ibid.

[4] Op Cit. Footnote 2.

CO_2 Sensors

According to Emmerich and Persily (1997)[5], CO_2-based DCV is most likely to be cost-effective when there are *unpredictable* variations in occupancy in a building and climate where heating and cooling is required for most of the year, and when there are low pollutant emissions from non-occupant sources[6]. The advantage of CO_2 -based DCV is if the CO_2 sensors are kept properly maintained and calibrated, accurate measurements of zone and outside air can be measured and Equations (3) and (4) can be used to accurately calculate the people in the zone, and the zone differential CO_2 setpoint (difference between the zone and outside air CO_2 concentrations), respectively, and ventilation can be provided to meet the exact requirements.

Relationship between Building Pressurization and IAQ

Building pressurization is an area of study by itself, and it is tightly linked to outside air intake and exhaust. The three parameters are inter-related so sequences need to address each. The three parameters are inseparable because of the following:

- The same components affect both variables. Outside airflow and building pressure are both affected by the operation of both fans and by the dampers in the mixing section. A change at any one of those components can be seen in the outside air intake and in the building pressure. (In fact, Fan Flow Tracking, a well known building pressurization strategy, is often proposed as a strategy for outside air intake control.)
- Building pressurization is the balance between intake and exhaust, so outside air intake is half of the building pressure phenomenon. One way a building pressurization system can fail is when the outside air intake goes to a value too high or too low for the exhaust system to track.
- Improper building pressurization leads to unplanned outside air intake. If the return flow is outside the proper range, the building draws uncontrolled outside air, either by infiltration in the space, or by reverse flow at the exhaust damper. Either way, the unplanned flow defeats whatever outside air intake control has been achieved. Figure 1 illustrates the effect of inaccurate building pressurization.

[5] Emmerich, Steven J. and Persily, Andrew K., PhD. 1997. Literature review on CO_2-based demand-controlled ventilation, *ASHRAE Transactions*, 103(2).

[6] Ibid. While CO_2-based DCV can control occupant-generated effluents effectively, it may not control contaminants from non-occupant sources, such as some building materials, and outdoor sources. The control of such non-occupant sources has to be designed for on a case-by-case basis and DCV may not apply to these zones.

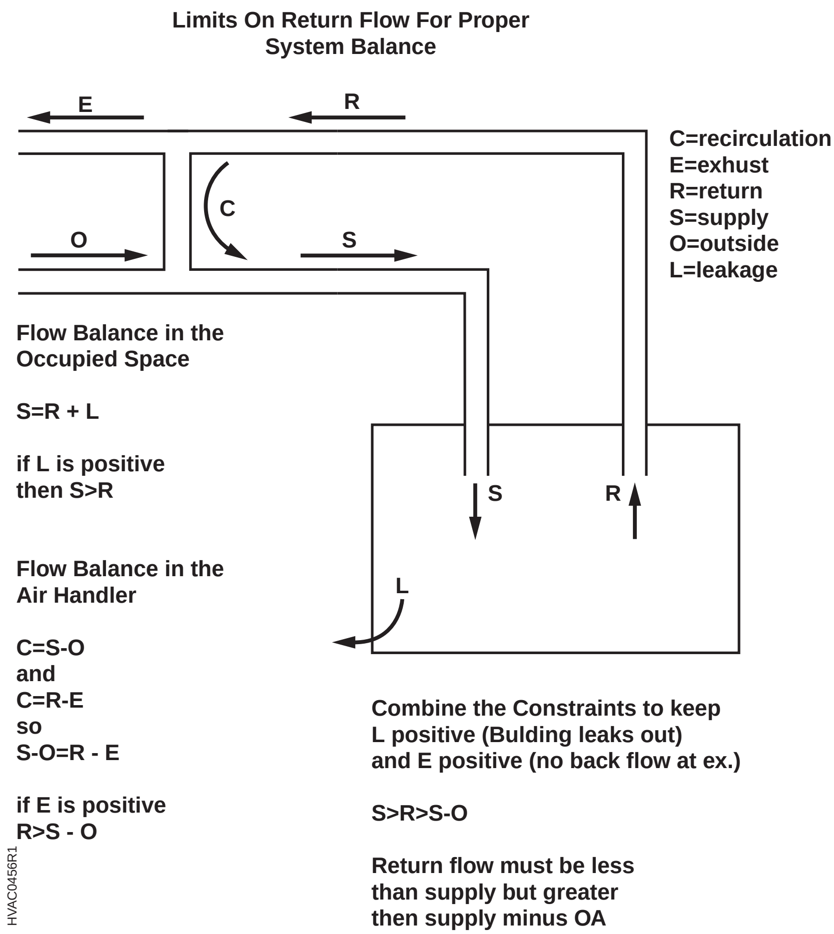

Figure 1. Limits on Return Flow for Proper System Balance.

Building pressurization has still more affects on IAQ. Negative building pressure causes infiltration of outside air into the occupied spaces. While outside airflow is generally good for IAQ, and infiltration is sometimes viewed as another source of ventilation air, there are also problems associated with infiltration. Common problems include the following:

- Infiltration brings in untreated air and can cause uncomfortable conditions in the occupied spaces, which then affects people’s perception of air quality.
- Humid infiltrating air can lead to mold and degradation of the building envelope. The effect in the occupied space is bad, but moisture deposited within the walls can be a disaster for IAQ and for the structure.
- Infiltrating air may be contaminated. Outside air intakes are supposed to be engineered to avoid the worst outside air, but this is impossible with infiltration.

The importance of these effects varies. For some buildings in cold climates, the situation is reversed. In those buildings, positive pressure drives moist indoor air into the envelope. The condensation then freezes and damages the structure. In this situation, the design engineers may decide that negative pressure is preferred.

Systems Serving Multiple Spaces

In a typical air distribution system, one air handler serves multiple terminals. Each terminal serves a particular room, or group of rooms, or part of a room. The separate rooms may be viewed as individual spaces with their individual outside airflow requirements. The central air handler has to draw enough outside airflow to satisfy all the spaces, but it can't individually deliver the required outside air quantity to each room. The outside air comes in and gets mixed with the return air, making it impossible to deliver a precise outside air quantity to a specific room.

If the outside airflow at the air handler is the sum of the requirements in each space, some spaces will get more outside air than they need and some will get less. If the outside air fraction for the air handler is set equal to the highest outside air fraction needed by any space, then they all get at least the minimum amount of outside air, but the system may use a lot of outside air and a lot of energy to treat it.

The ASHRAE Standard 62.1-2010 defines a middle ground between these two, reducing outside airflow as far as possible while maintaining the required outside airflow to each space. Follow the procedures in section 6.2.5 of ASHRAE 62.1-2010 to calculate the amount of outside air ventilation required for each zone of a multi-zone system. For each zone, a *zone air distribution effectiveness* factor, E_z, and a *system ventilation efficiency* E_v must be determined from using Tables 6-2 and 6-3, respectively, or use *Appendix A* for the determination of E_v.

A DDC control program with a Demand Control Ventilation strategy *can* be applied to multi-zone systems provided the following conditions are met:

- Airflow to each zone is controlled by separate VAV boxes.
- There is a method to determine change in occupancy for each zone.
- The outside air ventilation requirement is calculated for each zone, taking into account the zone air distribution effectiveness (E_z) and the system ventilation efficiency (E_v) according to ASHRAE 62.1-2010.
- The max VAV box airflow is set up to provide the ventilation required when the zone is at maximum occupancy.

Ventilation Rates and Requirements

The following sections discuss the codes, standards and ventilation rate values you need to know when setting up a DCV system.

Codes and Standards

The required ventilation rates are among the most basic design parameters for any HVAC design or retrofit. ASHRAE Standard 62.1: Ventilation for Acceptable Indoor Air Quality is probably the most referenced standard by jurisdictions and design professionals. (This standard is updated by ASHRAE every 3 to 4 years, the version number being designated by the year of the update after the number of the standard. For example, at the time of this writing, ASHRAE Standard 62.1-2010 is the latest version of the standard.)

Ventilation rates are set by local building codes, building standards, ASHRAE Standard 62.1, or a combination of the three, but local building codes usually have jurisdictional priority. In the New York City area in the U.S., local building codes do call for the use of *ASHRAE Standards 90.1* and *62.1* for all new construction projects, and major renovation projects for existing buildings. Although, the use of *ASHRAE Standards 90.1* and *62.1* in local building codes is prevalent throughout the U.S. for new construction and major renovation projects, it is certainly not universal, especially in more rural areas. If you are involved in setting the rates, you need to choose the highest value from all of those sources. If you are not involved in setting the rates, get explicit written instruction on what the rates are and who has taken responsibility for them.

Many building codes use the International Mechanical Code (IMC) as a model. Representatives of the International Code Council have managed this document since 2003. The IMC uses ASHRAE's Standard 62.1 table of ventilation rates for various types of spaces (Table 6-1). An excerpt of this table is shown later in this document.

Demand Control Ventilation and LEED® Green Building Rating Systems

The primary reference for the design, construction, and operation of green buildings for the U.S. market is the U.S. Green Building Council's *Leadership in Energy and Environmental Design* (LEED®) program. A companion organization called the *Green Building Certification Institute* (GBCI) is responsible for rating buildings according to green building design, construction and operation standards, and accrediting professionals. A Demand Control Ventilation operating strategy can play a prominent or supporting role in several LEED® prerequisites or credits according to the *LEED 2009 Green Building Operations and Maintenance* and the *LEED 2009 Building Design and Construction* Reference Guides.

In the IEQ section of the LEED 2009 New Construction and Major Renovation rating system, the designer is required to meet the requirements of Sections 4-7 of ASHRAE 62.1-2007, Ventilation for Acceptable Indoor Air Quality.

Although CO_2 monitoring is not a prerequisite, they do offer an optional Credit (IEQ C1). The credit calls for permanent monitoring of ventilation and notifying an operator when the ventilation deviates from design by more than 10%. Monitoring systems can use airflow values or CO_2 levels. The credit also requires that CO_2 be monitored in densely populated zones, such as classrooms, conference rooms and training rooms.

In the EA section of LEED 2009-NC, the designer is required to exceed the baseline energy performance of ASHRAE 90.1-2007. Part of the baseline requirements is to apply DCV to high occupancy spaces, with a few exceptions.

Overlapping investment can provide more benefits. DCV does not require that CO_2 sensing be used, but, if CO_2 sensing is used, it contributes to the Energy prerequisite (EA PC1) and to the IEQ optional credit (IEA C1).

Likewise, if more zones are monitored under the IEQ C1 using CO_2 sensors, then all of those zones can easily be converted to DCV sequences and possible contribute to more EA optional points for higher energy efficiency.

The LEED 2009 Existing Buildings Operations & Maintenance rating system has similar credits in IEQ and EA that can be supported by DCV and CO_2 monitoring.

Ventilation Rates

The following values are needed to design a demand controlled ventilation system:

Exhaust and Exfiltration Rate – the flow required to pressurize the building. Most buildings have exhaust fans that are separate from the air handler. Examples include exhaust fans for restrooms, kitchens and photocopy rooms. The outside airflow must be enough to balance all the exhaust devices, plus enough to generate the desired exfiltration to the surrounding spaces, including the outdoors. Building pressure is usually controlled through modulation of the return flow, exhaust flow or relief flow, but control of building pressure is only possible if the outside airflow is large enough to balance exhaust and exfiltration.

Design Ventilation Rate – the flow required at full occupancy. This value should be calculated using Table 6-1 in ASHRAE Standard 62.1-2010 (this table is reproduced, in part, as

Table 1 in this document). For most types of spaces, the ventilation requirements are expressed in cfm (L/s) per person for the people component and cfm/ft^2 (L/s/m^2) for the building component. To set the rate, characterize the use of the space and determine the design occupancy by getting the customer's estimate of the number of occupants expected and the floor area of the space. Table 6-1 of ASHRAE Standard 62.1-2010 lists default occupancies (in number of people per 1000 ft^2 or per 1000 m^2) for many types of spaces. The IMC prohibits using an occupancy number less than ASHRAE's estimate without "approved statistical data".

Minimum Ventilation Rate – Table 6-1 in *ASHRAE Standard 62.1-2010* specifies a minimum ventilation rate based on both the number of people in a space and for the effluents generated within the space. This minimum ventilation rate is specified according to the following equation:

$$V_{bz} = R_p \cdot P_z + R_a \cdot A_z \tag{1}$$

[Eqn. (6-1) in ASHRAE 62.1-2010]

Where:

V_{bz} = the breathing zone outdoor airflow, cfm (L/s).

R_p = Outdoor airflow rate (cfm, L/s) required per person as specified in Table 6-1.

These values are based on adapted occupants (occupants adapted to the zone environmental conditions).

P_z = Zone population: the largest number of people expected to occupy the zone during typical usage. If the number of people expected to occupy the zone fluctuates, P_z may be estimated based on averaging approaches described in Section 6.2.6.2.

If P_z cannot be accurately predicted during design, it shall be an estimated value based on the zone floor area and the default occupant density listed in Table 6-1.

R_a = Outdoor airflow rate (cfm, L/s) required per unit floor area (ft^2, m^2) as specified in Table 6-1.

A_z = Zone floor area: the net occupiable floor area of the zone (ft^2, m^2).

Table 1. Selected Outdoor Air Requirements for Ventilation.[7]

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Occupant Density[8] #/1,000 ft^2 or #/m^2	Combined Outdoor Air Rate[9]		Air Class
	Cfm/person	L/s/person	Cfm/ft^2	L/s/m^2		Cfm/person	L/s/person	
Office Buildings								
Office space	5	2.5	0.06	0.3	5	17	8.5	1
Reception areas	5	2.5	0.06	0.3	30	7	3.5	1
Main entry lobbies	5	2.5	0.06	0.3	10	11	5.5	1
Miscellaneous spaces								
Computer	5	2.5	0.06	0.3	4	20	10.0	1
Pharmacy (prep. Area)	5	2.5	0.18	0.9	10	23	11.5	2
Public Assembly Spaces								
Auditorium seating area	5	2.5	0.06	0.3	150	5	2.7	1
Libraries	5	2.5	0.12	0.6	10	17	8.5	1
Lobbies	5	2.5	0.06	0.3	150	5	2.7	1

In a multi-zone system, the Equation 1 above is applied to each zone individually. The zone terminal unit is set up to meet the requirements of the zone. The AHU that feeds the zone terminal units has to provide enough ventilation air to meet the accumulated ventilation requirements for all of the zones.

DCV is meant to reduce the human component of the fresh air ventilation requirements when fewer than the design number of people are occupying a space during occupied hours. The fresh air ventilation requirements to dilute the building effluent component should be regarded as the low limit of the fresh air ventilation when there are no occupants within the space during occupied hours.

[7] Adapted from Table 6-1 in ASHRAE Standard 62.1-2010.

[8] Occupant density: The default occupant density shall be used when actual occupant density is not known.

[9] Default combined outdoor air rate (per person): This rate is based on the default occupant density.

DCV Savings Opportunity

The primary purpose of DCV is to save energy, not to improve IAQ. In fact, the IAQ can either improve or worsen, depending on the baseline ventilation rate. For example, the *LEED 2009 Green Building Design and Construction* (IEQ Credit 2) and *LEED 2009 Green Building Operations and Maintenance* (IEQ Credit 1.3) reference guides specifies that IAQ will improve if outdoor air ventilation rates for all air handling units serving occupied spaces can be increased by at least 30% above the minimum required by ASHRAE Standard 62.1. One point is awarded in each rating system if it can be shown that the above outdoor airflow rates at met.

Ventilation rates affect the cost of operating a building. When outside air is brought in for the sake of IAQ, the system consumes energy to condition that air. The more outside air is required, the greater the energy expense. This motivates some customers and HVAC engineers to reduce that expense if possible, as long as they can continue to meet codes.

ASHRAE Standard 62.1, the IMC, and some local codes specify most ventilation rates in terms of the number of occupants. As people come and go, the number of occupants in a particular space varies. This suggests that the ventilation rate could go up and down with the occupancy. Demand Controlled Ventilation means just that: when the space is full, ventilate at the highest rate required. When the space is less occupied, reduce ventilation to correspond to the number of occupants at the time.

ASHRAE Standard 62.1 has been officially interpreted to support that concept. The IMC specifically says the system must be designed to ventilate at the maximum expected occupancy, but may be operated according to actual occupancy at the time. Both of these documents support the concept of DCV, in which the ventilation rate is varied to meet changing occupancy. Local codes may not address the question. Consider getting a local ruling before designing a DCV system since local building codes usually hold jurisdictional standing.

Compared to a system that ventilates at the design rate all the time, a DCV system can save significant amounts of energy (documented studies show up to 70% savings for some zone types and occupancy variations). The savings, however, varies in different buildings. Factors include the following:

- The occupancy pattern – a system with many operating hours at low occupancy offers a greater opportunity than one that usually either shuts off, or runs at full occupancy. A movie theatre is an example of a space where the occupancy varies greatly, while an office with workers on a uniform schedule is the other extreme. This kind of workplace is becoming less common. Many buildings now run evenings and weekends with light usage.
- Weather – cities in Minnesota and Florida are likely to have higher expenses than a city like San Diego, and all other factors being equal, will make DCV less cost effective to implement. However, even cold or hot/humid climates have seasons when outside air is less expensive to use than re-circulated air.
- The type of air distribution HVAC system used to heat and cool the building, and the price of energy.

On this last point, DCV is most feasibly implemented on *Single-Zone (Supply) Systems* (constant volume reheat, single-duct VAV, single-fan dual duct, and multi-zone systems). On these systems, the calculations in Equations (6-1) through (6-8) in *ASHRAE Standard 62.1-2010,* and Equations (A-1) and (A-2) in *Appendix A* of that standard are fairly straightforward and can be performed in the controller program. DCV can also be implemented in Dedicated Outdoor Air Systems (DOAS) and multi-zone recirculation (VAV) systems. Procedures are described in ASHRAE 62.1-2010 Sections 6.2.4 and 5. Excerpts are shown in Chapter 3 of this document. **DCV can also be implemented in Secondary Recirculation Systems (such as dual-fan dual-duct, and fan-powered mixing box systems).** However**,** the ASHRAE Standard 62.1 calculations and procedures needed to implement DCV are much more complex and are not described in this guide. Consult the *ASHRAE Standard 62.1-2010* Appendix A and the *User's Manual* for *ASHRAE Standard 62.1-2010* for the equations and procedure necessary for implementing DCV for secondary recirculation systems.

Therefore, a DCV system is a typical energy conservation strategy and is most cost effective on single-supply systems for large spaces with variable occupancy, such as lecture halls, auditoriums, gymnasiums, but can be applied to smaller zones such as conference rooms, meeting rooms and class rooms (college or adult only – do NOT attempt to implement DCV for K – 12 schools since ASHRAE Standard 62.1 applies to body mass and *met levels* for <u>adults</u> only). The HVAC engineer must estimate the annual savings before committing to a DCV system.

Paragraph ***6.4.3.9 Ventilation Controls for High-Occupancy Areas*** in ***ASHRAE Standard 90.1-2010*** states that DCV ***<u>must</u>*** be implemented for all spaces larger than 500 ft^2 and with a design occupancy for ventilation of greater than 40 people per 1000 ft^2 of floor area that has one or more of the following: (a) an air-side economizer, (b) *automatic* modulation control of the outdoor air damper, or (c) a design outdoor airflow greater than 3000 cfm. Note that there are four exceptions to this requirement:

1. Systems with exhaust air energy recovery complying with section 6.5.6.1 of ASHRAE Standard 90.1-2010.
2. Multiple-zone systems without DDC of individual zones communicating with a central control panel.
3. Systems with a design outdoor airflow less than 1200 cfm.
4. Spaces where the supply airflow rate minus any makeup or outgoing transfer air requirement is less than 1200 cfm.

Building and Zone Types Best Suited for CO_2-based DCV

According to Emmerich and Persily (1997)[10], there is a fairly wide consensus on when to use CO_2-based DCV. Most of the discussions of CO_2-based DCV mention the following building and zone types as good candidates for such control:

- Public buildings, such as cinemas, theaters, and auditoriums
- Educational facilities such as classrooms and lecture halls
- Teaching labs
- Meeting rooms

[10] Op. Cit. Footnote 5.

- Retail establishments

CO_2-based DCV is most likely to be effective where *unpredictable* variations exist in occupancy for a building and climate where heating or cooling is required for most of the year, and low pollutant emissions from non-occupant sources exist. For *predictable* variations in occupancy, ventilation based on a time-of-day schedule is generally most cost-effective, while for small zones, such as small conference rooms or private offices, ventilation based on an occupancy sensor is often the most cost-effective approach.

Savings Potential with CO_2-based DCV

Numerous studies have documented the energy savings performance from CO_2-based DCV. Case studies based on both field tests and computer simulations show a wide variance in the energy savings potential of DCV.

A literature review of CO_2-based DCV was performed by Emmerich and Persily (1997)[11] that included case studies based on both field tests and computer simulations, studies of sensor performance and location, and discussions of the application of the approach. Field test energy savings results included the following:

Many of the following field tests were early studies of CO_2-based DCV when the science of DCV was in its infancy. A significant shortcoming of many of these early studies was the inclusion of little or no description of the control algorithm investigated in the study. These omissions made it hard to evaluate which approaches worked, and which did not. In several of the studies cited below, the indoor air CO_2 concentration was often not high enough for the CO_2 control system to operate. This may be due in part to the relatively low occupant density in office buildings. Also, many of these early studies cite the relationship of CO_2 control with indoor air quality (IAQ). As we have seen, IAQ is often more a matter of facilities management and indoor pollutant sources, such as the generation of Volatile Organic Compounds (VOC's) from certain building materials, floorings, seals, and adhesives. DCV addresses ventilation only but ventilation is only one component of IAQ (refer to section on **Error! Reference source not found.**).

1. Two floors of an office building in Montreal, where one floor was equipped with a CO_2-based DCV system while the other floor served as a control space (Donnini et al. 1991; Haghighat and Donnini 1992).[12,13] **Annual energy savings of 12% were measured for the floor with DCV**. Occupants of the DCV floor complained significantly more about the indoor environment than occupants of the control floor for part of the year.

[11] Op. Cit. Footnote 5.

[12] Donnini, G., F. Haghighat, and V.H. Hguyen. 1991. Ventilation control of indoor air quality, thermal comfort, and energy conservation by CO2 measurement. *Proceedings of the 12th AIVC Conference Air Movement & Ventilation Control within Buildings*, pp. 311 – 331. Coventry, U.K.: Air Infiltration and Ventilation Centre.

[13] Haghighat, F., and G. Donnini. 1992. IAQ and energy-management by demand-controlled ventilation. *Environmental Technology* 13: 351 – 359.

2. Another frequently cited study took place in a Minnesota high school (Janssen et al. 1982)[14]. The ventilation system used CO_2 and temperature to control outdoor air and had separate dampers for temperature and CO_2 control. The measured energy savings were about 20%. The occupant questionnaire showed that the subjects felt warmer with increased CO_2 concentrations despite the fact that there was no measurable temperature difference with and without CO_2 control.
3. A study of two Finnish public buildings, one that had CO_2-controlled ventilation, included measurements of radon, particulates, and CO_2 (Kummala et al. 1984)[15]. No description of the algorithm was reported. Daily energy savings were estimated to be 13% to 20%.
4. Auditoriums are good examples of ideal spaces for DCV because of their wide diversity in occupant density. One such study took place in an auditorium with CO_2 and timer control of ventilation at the Swiss Federal Institute of Technology in Zurich (Fehlmann et al. 1993)[16]. The ventilation system had two stages of airflow capacity, with the first stage coming on at a CO_2 concentration of 750 ppm and the second stage coming on at a CO_2 concentration of 1300 ppm. The second stage would turn off at a CO_2 concentration of 1100 ppm and the first stage would turn off at a CO_2 concentration of 600 ppm. With ventilation controlled by CO_2, run time was 67% of the run time with timer control in summer and 75% in winter. Energy consumption with CO_2 control was 80% less in summer and 30% less in winter.

The above study is an example where CO_2 control saved on both fan (electric) energy and coil (thermal) energy. In this case, fan electrical savings was due strictly to the control strategy of using a two-stage fan for CO_2 control. Most DCV systems today are implemented on systems with single-stage fans and so savings are derived solely based on a reduction of the coil thermal load by bringing in less outside air that needs to be conditioned to satisfy ventilation requirements. The Krarti and Al-Alawi study (2004) described below confirm this.

One of the more comprehensive studies using computer simulation was performed by Brandemuehl and Braun (1999)[17] with a building model, space conditioning model, and equipment model. Their study was performed via hourly simulation models using climate-specific weather data on four different types of commercial buildings: office (6600 ft^2 floor area), large retail store (80,000 ft^2 floor area), school (9600 ft^2 floor area), and a sit-down restaurant (5250 ft^2 floor area) at 20 locations, selected to provide a good cross-section of climates within the United States: Boston, New York, Washington, D.C., Atlanta, Miami, Madison, Chicago, Pittsburgh, Nashville, Lake Charles, Minneapolis, Topeka, Denver, Ft. Worth, Houston, Seattle, Sacramento, Los Angeles, Albuquerque and Phoenix. Hourly simulations were performed for 480 different cases (6 ventilation strategies, x 4 buildings x 20

[14] Janssen, J.E., T.J. Hill, J.E. Woods, and E.A.B. Maldonado. 1982. Ventilation for control of indoor air quality: A case study. *Environment International* 8: 487 – 496.

[15] Kulmala, V., A. Salminen, G. Graeffe, K. Janka, J. Keskinen, and M. Rajala. 1984. Long-term monitoring of indoor air quality and controlled ventilation in public buildings. *Proceedings of the 3rd International Conference on Indoor Air Quality and Climate* 5: 435 – 441.

[16] Fehlmann, J., H. Wanner, and M.Zamboni. 1993. Indoor air quality and energy consumption with demand controlled ventilation in an auditorium. *Proceedings of the 6th International Conference on Indoor Air Quality and Climate* 5: 45 – 50.

[17] Brandemuehl, Michael J., PhD, PE, and Braun, James E., PhD, PE. 1999. The impact of demand-controlled and economizer ventilation strategies on energy use in buildings, *ASHRAE Transactions*, 105(2).

locations. **Only single-zone systems with Constant Air Volume (CAV) systems were studied.** This eliminated the fan energy from consideration as a source of savings; it also eliminated the complication of modeling large, multi-zone spaces, and meant that simultaneous heating and cooling did not exist. Baseline conditions were modeled with fixed minimum outside air damper position and no economizer operation. Minimum ventilation rates were based on ***ASHRAE Standard 62.1-1989*** (the standard in effect at the time). Two different economizer options were modeled: dry-bulb and enthalpy. In both economizer modes, the ventilation flow rate is modulated between the minimum and maximum (wide open) values to maintain a specified setpoint (that is, 55°F) for the mixed air temperature supplied to the equipment. For both economizer models, dry-bulb and enthalpy values were assumed to be 100% accurate[18]. The model considered packaged rooftop equipment with simple on/off control. Specifically, the analysis included air conditioners with gas furnaces and heat pumps with electric auxiliary heat. The fan is on during all hours of occupancy, and the compressor or heater cycles on and off to maintain the zone temperature at its setpoint. The results of this study derived the following general conclusions:

- **DCV, when combined with different economizer control strategies (e.g. enthalpy economizer versus dry bulb economizer) can increase the overall savings potential, and sometimes increases it significantly.** Generally, DCV when combined with enthalpy economizer provided much greater energy savings potential than DCV when combined with dry-bulb economizer. In fact, in one city studied (Los Angeles), for the sit-down restaurant, there was **<u>no</u>** savings associated with DCV and all the savings were associated enthalpy economizer control. This is due to Los Angeles' mild, dry climate, and the fact that all cooling loads could be met with enthalpy economizer operation. Enthalpy economizer operation, assuming enthalpy values can be sensed with 100% accuracy, minimizes coil energy in every case. (See footnote 18 for discussion of how sensor accuracy can impact savings.)
- The savings potential associated with demand-controlled ventilation is much more significant for heating than for cooling, since economizer operation does not play a role.
- The savings associated with different ventilation strategies are strongly dependent upon the building type.
- The savings for economizer and demand-controlled ventilation were significantly greater for the retail store (36%), restaurant (45%), and school (47%) than for the office building (23%).
- The general trend of energy savings is similar to those discussed for Madison, Atlanta, and Albuquerque. Demand controlled ventilation delivers dramatic energy savings during the heating season. Greater savings occur when the heating requirements associated with ventilation are a large fraction of the total. **Savings for the retail store and restaurant were greater than 85% for all locations; savings for the school were greater than 70% in all locations. The heating loads for these buildings are dominated by ventilation loads. The office building is mostly dominated by envelope loads and show considerably less savings. For most locations with significant heating requirements, the savings for the office building were approximately 30%.**
- **The greatest incremental savings for demand controlled ventilation occur in the southeastern U.S., where high humidity reduces the benefits of economizer cooling.**

[18] Taylor (2010) has shown that sensor error and calibration maintenance costs (for both dry bulb and humidity sensors) can have a significant impact on economizer savings.

Later studies on **conventional VAV multi-zone systems** have shown a lower savings potential when both HVAC system energy use and the indoor air quality were modeled under a comprehensive simulation environment capable of modeling transient effects (Krarti and Al-Alawi 2004)[19]. IAQ was modeled using a contaminant transport model adapted from the work of Knoespel et al. (1991)[20]. This was the first major study where the impact of design and/or operating parameters of DCV controls were extensively explored. The air handler system modeled consisted of a central air handling fan with VAV terminal units with reheat coils located in the zones. The air handling unit itself consisted of a VAV supply fan with a cooling coil, preheat coil, and an outside air economizer cycle. Two zones were modeled: an office area and a conference room. The conference room was centered in the middle of the building. The model was run using Typical Meteorological Year (TMY) weather data for June 1 from four cities with widely different climates: Miami, Phoenix, Boulder/Denver, and Madison, WI. For the base-case control strategy, the outdoor air damper position was assumed to be fixed to satisfy ventilation requirements as specified in ASHRAE Standard 62.1-1999[21]. They reported that **chiller energy savings was 24.4% for Miami, 17.1% for Phoenix, -6.3% for Boulder/Denver, and 12.9% for Madison**. The energy penalty for Boulder/Denver is due to the fact that providing more outside air is actually beneficial for Boulder/Denver (during June 1).

Fan energy savings for each of these cities was negligible. This was due to the fact that a single-stage fan system was modeled with a conventional DCV strategy, so the fan had to run at the same speed and amount of time whether or not a DCV was implemented. Their paper showed that combining DCV with either temperature or enthalpy air-side economizer control ensures that cooling energy savings can be achieved for most locations -- **this study showed that percent reduction in thermal energy for the conditioning of the outside air for the Boulder/Denver, Colorado, area was 38% and for the Phoenix, Arizona, area was 17% compared to DCV without economizer control.**

When simulations were carried out for an entire year combining DCV with temperature or enthalpy air-side economizer control, savings were more dramatic for Boulder/Denver. **Annual cooling load energy savings for Boulder/Denver were 38% and 17% for Phoenix.**

[19] Krarti, Moncef, PhD, PE, and Al-Alawi, Mohsin, PhD. 2004. Analysis of the impact of CO_2-based demand-controlled ventilation strategies on energy consumption, *ASHRAE Transactions*, 110(1).

[20] Knoespel, P., J. Mitchell, and W. Beckman. 1991. Macroscopic model of indoor air quality and automatic control of ventilation system. *ASHRAE Transactions*, Vol 97, pp. 1020 – 30.

[21] ASHRAE Standard 62.1-1999 was the current ventilation standard in effect at the time of this paper's publication.

DCV Sequences Overview

Sensor Locations

CO_2 sensors should be installed in the space[22] (technically, in the breathing zone[23]) being controlled, not in the return air duct or some other location. This is especially true for multiple-zone systems. Return air sensing for multiple-zone systems has the effect of averaging the variations of CO_2 concentration of the various zones and precludes the ability to respond to the fresh air requirements in the individual zones. Moreover, locating the sensor in the return air duct may result in inaccurate CO_2 readings due to short-circuiting of supply air with return air since some of the supply air does not reach the occupants[24].

Picking Zones

DCV is most cost effective when zone population varies widely from design throughout the normal occupied hours of the day. Zone sensing means that the designer has recognized that the space will be used non-uniformly. People are expected to enter and leave the zones at times that vary throughout the occupied space. Some situations obviously call for zone sensing. One example is a row of conference rooms served by one air handler that will be filled and vacated at different times. Another example is a group of classrooms[25] that have different schedules; some rooms are empty, while others are full.

[22] Both *California Energy Efficiency Standard for Residential and Commercial Buildings, Title 24 Part 6* and *LEED 2009 Green Building Operations and Maintenance* require that the CO_2 sensors be located in the space.

[23] *ASHRAE Standard 62.1-2010* defines breathing zone as "the region within an occupied space between 3 and 72 inches (75 and 1800 mm) above the floor and more than 2 feet (600 mm) from the walls or fixed air conditioning equipment." *LEED 2009 Green Building Operations and Maintenance* defines the breathing zone as being between 3 and 6 feet above the floor.

[24] This can happen, for example, if the supply duct lies in the return air plenum. Then, any air that leaks out of those ducts enters the return air stream and lowers the return air CO_2 reading. Short-circuiting also occurs within the occupied space since some of the air leaving a diffuser never reaches the occupants and goes directly back to the return air grill.

[25] DCV can be applied in college-aged or adult classroom only. Do not attempt to implement DCV for K – 12 schools. ASHRAE Standard 62.1 applies to body mass and met levels for adults only.

Zone Control vs. Central Control of Outside Air Intake

In most air conditioning systems, supply flow rates are set at the terminals (zone) and the outside air fraction is set at the air handler (central). The outside airflow rate to a particular zone depends on both variables, so it is possible to control ventilation from either location. Central control sets the outside air fraction for the whole system, without the ability to single out one zone for more outside air. This may result in unnecessary ventilation in some zones. Zone control adjusts the airflow in one zone, without changing the flow rates in the other zones. However, if the outside air fraction at the system is too low, the zone controller will increase the supply flow without getting the demanded ventilation. Zone DCV can also disrupt temperature control. Some terminals don't have reheat, and the added cold supply air can't be tempered[26]. The choice depends on the expected use of the space and on design and operation of the air conditioning system.

Combination: Zone CO_2 Sensing with Central Control of Outside Air Intake

If occupancy from zone to zone varies, and the fully occupied zones will draw most of the supply air, then central control makes sense. The high outside air fraction delivered to the lightly occupied zones will not be expensive because the flow rate will be low. In this case, when the CO_2 being sensed in the zones exceeds the CO_2 setpoint for that zone, a program must **temporarily override** the AHU minimum outside air intake CFM to allow the damper to modulate to a more open position to ensure adequate ventilation. The temperature control is maintained via the heating and cooling coils. Once the measured CO_2 in the zone falls below its setpoint, the AHU minimum outside air damper returns to its minimum ventilation position.

Combination: Zone Control with Design Ventilation at Central System

In this combination of control, DCV is performed in individual zones with a programmable terminal equipment controller application (for example Siemens PTEC). Programming would need to be written in the zone controller to calculate the zone differential CO_2 setpoint

The designers can choose to perform the DCV only at the Zone level. In this case, the program at the terminal unit can provide minimal ventilation when there is zero or minimal population in the space and reset up as the population increases. A variety of methods can be used to determine the increased occupancy.

This method assumes that the Central AHU is ventilating to the design population at all times. This will result in over-ventilation of most zones. The over-ventilation can then be used to dilute the DCV zones when they need more ventilation.

This method is most applicable when the population of most of the building is predictable and consistent and there are only a few zones of high-occupancy using DCV.

This method will meet most codes, but the result will be very little energy savings. The energy savings is mostly affected at the ventilation changes at the Central AHU.

[26] For this reason, DCV is not recommended to be implemented on fan systems without terminal reheat in cold climates.

Combination: Zone Control and Central Control Combination

It is possible to apply zone control at some terminals and central control at the air handler. A system that serves closed offices at the perimeter of the building, and an open space in the middle is a good example. The closed offices have their own individual demands, and the open area has a more uniform demand. Zone control can serve the closed offices, (which are likely to have reheat) and central control can serve the interior space (which may not have reheat).

Combination: Zone Control and Central Control Working Together

It is possible to apply zone control at some or most of the zones and then use that information to set the ventilation at the AHU. The AHU only has to ventilate for the population that can be predicted or sensed. If more zones are sensed, then the AHU can vary its ventilation to follow the zones, instead of working from a predetermined setting.

The AHU can have a range of ventilation CFM that it provides. Typically the range is from the minimum at the predictable and consistent population and the design population. The AHU can reset ventilation between these two settings based on the accumulation of what is happening at the zones. If most zones are sensing that the occupancy is low or zero, then the ventilation at the AHU will be low. If most zones are active or there are many high occupancy zones filled with people, then the zones will signal to the AHU to reset the ventilation higher.

The method is most applicable to buildings with varying or unpredictable occupancy levels. It takes methods that are already being applied to meet codes and applying them to additional zones to save energy. This method can provide the highest level of energy savings. Using a variety of methods at the zones to determine population (schedules, occupancy sensors, population counters, CO_2 sensors), the investment can be minimized to achieve additional energy savings.

Air-side Economizers and Ventilation Overrides

Air-side economizers open up the ventilation dampers to use the outside air as a cheaper method to cool a building. When this sequences starts, the building or systems by definition of the economizer enter a sequence of over-ventilation. In this case, it is not a penalty, but a benefit, because of the savings on the cooling.

In cold climates, economizers vary in a range between full open to outside air and the minimum need for ventilation. Because of this, the minimum ventilation calculation is still performed by the program. As the outside air gets colder, less is needed to meet the discharge setpoint of the unit. The mixing dampers will continue to bring in less outside air as the outside air gets colder. The dampers will stop closing at the point where the outside air meets minimum ventilation air volume.

In very cold weather, if the mixed air continues to drop below setpoint because the minimum ventilation air is very cold, then a preheat coil is enabled to temper the air to meet the discharge setpoint.

As an added level of protection, if the mixed air temperature drops low enough that it approaches the freezing point of a coil, then a “Mixed Air Low Limit Sequence” will reduce the outside air intake to pre-empt a trip by the freezestat. This sequence is not normal operation and is meant to be a temporary condition to protect equipment from damage. If this condition is re-occurring to a point where the comfort of the space deteriorates, then measures should be taken to increase the heating capacity to prevent this condition.

Use of a Purge Cycle

In any building, the occupants and their activities generate a portion of the air contaminants. The building and its contents generate another portion of the contaminants. The “people” and “floor area” components of the fresh air ventilation requirement are seen in Equation (1) of this document (Eq 6-1 in ASHRAE 62.1-2010). The ventilation rate selected for use when the space is fully occupied should be enough to dilute all the contaminants. When the people leave, and the air handler system shuts down[27], the building continues to generate contaminants. The concentration increases while the system is off, and can be high by the time the system starts in the morning. When the ventilation starts, the concentration of contaminants will begin to fall back to desired levels, but this is a gradual process. For some time, occupants will experience higher concentrations than desired. The higher the ventilation rate, the faster the contaminants are diluted. In most applications, if the system starts up at the Design Ventilation Rate (DVR), contaminants will be quickly diluted. However, a DCV system is likely to start at a low ventilation rate. This extends the time required to dilute the contaminants that built up while the system was off. A fresh air purge before the space is occupied reduces exposure to those contaminants.

Although ASHRAE 62.1-2010 does not specifically mention the need for a purge cycle to vent the building effluents from the space after a prolonged period of vacancy, it suggests that ventilation should start before occupancy. For example, at night, if an office space is unoccupied, and the ventilation system can be turned off, then it should be scheduled to turn on before the building actually becomes occupied.

The process of diluting built-up contaminants was analyzed and presented in ASHRAE Standard 62-1989R and the following equation can be used to determine the minimum length of time in hours required to flush the zone effluents for a pre-occupancy ventilation.

$$t_L = \frac{1.5V_B}{V_L} \tag{2}$$

Where:

t_L = the ventilation lead time in hours before occupancy begins.

V_B = the volumetric ventilation rate of the zone.

V_L = the volumetric ventilation rate for the pre-occupancy period.

[27] Due to the “floor area” component of the fresh air ventilation requirement, ASHRAE Standard 62.1 states that the ventilation system <u>cannot</u> shut off during normal occupied hours. However, the ventilation system <u>can</u> be shut off during unoccupied hours only if there are no occupants in zone.

Methods of Controlling Building Pressure

A slight positive building pressure (0.005 to 0.08 inches water column) is generally desired to reduce infiltration of unconditioned outdoor air. Building pressure is controlled by balancing the quantity of outside air intake with the quantity of exhaust air. Three building pressure control concepts are applied to VAV systems. All methods depend on the system bringing in enough outside air that the pressure can be regulated with the exhaust or return flow. Each method can be integrated with the DCV and minimum ventilation controls described in *Chapter 2, Concept and Sequence of Operation*.

See the following for more information:

- 2011 ASHRAE HVAC Applications Handbook, Chapter 47 – *Design and Application of Controls, Building Pressurization,* pages 47.8 – 47.9*.*
- Avery, Gil., *The Instability of VAV Systems*, Heating/Piping/Air Conditioning, Feb. 1992.

Fan Signal Tracking

Fan signal tracking is a completely open-loop method. It uses no measurements and the signal that drives the return fan is calculated directly from the supply fan signal. The concept works on the assumption that the fan speed signals are related closely enough to the fan flow values, that coordinating them will cause the flows to match. This method does not respond to other equipment changes, such as remote exhaust fans starting or stopping. This method also neglects changes at the building envelope caused by wind, stack effect and doors opening. The relationship between the supply and return speeds should be set when the system is commissioned. Pressure tests indicate the right return fan speed for a given supply fan speed.

The DDC program often uses a very simple relationship. For instance, the return fan speed may be 90% of the supply fan speed. There may be buildings where such a simple calculation is acceptable, but it is unlikely that fans and duct systems are so similar that a fixed ratio will result in effective pressurization.

Fan Flow Tracking

Indirect building pressure control uses duct or fan airflow measurements to control a fixed differential air volume by modulating dampers, fan speed, or discharge rates. Because return air is typically the controlled variable, and its rate is set to track the normal changes in VAV supply at a fixed rate, this method is referred to as *return fan* or *fan airflow tracking*. The airflow differential setpoint is often determined empirically during commissioning as that needed to maintain a slight positive pressure with doors and windows closed. Fan flow tracking closes a loop to eliminate some of the variables affecting building pressure. Flow stations are applied to the supply and return fans. A flow tracking PID loop drives the return fan to the speed that gives the desired offset between supply and return fan flows. This is a more complicated system, with more parts to purchase, install, and calibrate. Also, some people find the PID loop difficult to tune. This method does not assume any relationship between the fans or the duct systems. It can respond to other fans cycling if the other flow values are included in the calculation. This method does not respond to changes at the building envelope. If the flow offset needs to pressurize the building changes, then the building pressure changes.

Static Pressure Control

Static pressure control closes a different loop, eliminating more of the building pressure variables. A pressure sensor measures the difference between one spot inside and one spot outside the building. Both the inside and outside static pressure measuring locations must be selected carefully. The inside static pressure measuring location must be selected away from openings to the outdoors, elevator lobbies, and other locations where it can be affected by wind pressure and drafts. Stack effect also impacts the reading for tall buildings. The outdoor static pressure measuring location must typically be located 10 to 15 ft above the building and oriented to minimize wind effects from all directions. Even with good sensor port locations, pressure readings can fluctuate and should be buffered before using them for control.

A control loop reads the static pressure as its input and drives the return or exhaust fan or damper to hold a fixed pressure difference.

This method responds to everything that affects building pressure, which is both its weakness and its strength. This method does not depend on a known relationship between the fans or ducts. It responds to remote exhausts without additional calculations. This method responds to changes at the building envelope. If wind or stack effect changes the size of the flow offset needed to pressurize the building, this system responds. It responds to doors opening, and wind blowing on the sensors, which cause incorrect readings.

The method is preferred by many of the people who write about HVAC controls, but can be very time consuming and problematic for the installers and programmers to make work and commission in all seasons, weather, and loads.

Controlling Outside Air Intake

The HVAC industry has gotten serious about the need to regulate the intake of outside air into air handling systems. It has been widely reported that some of the most popular methods are often ineffective so many new approaches have been proposed. All approaches face the same difficulty; the typical outside air intake is a hard place to accurately measure airflow.

Old (Discredited) Approach: Minimum OA Damper Setting

This used to be the most common approach to minimum outside air control but is now widely discredited since outdoor airflow depends on fan speed and/or the suction pressure in the mixed air plenum as well as the opening percentage of the outdoor damper. Therefore, in a VAV system a fixed damper position does not correspond to a fixed outdoor airflow.

Standard Approach: Fan Tracking

The outside air intake problem has been addressed by some people by relying on the flow stations and flow tracking system applied to the building pressurization problem (see Levenhagen, *Control Systems that Comply with ASHRAE Standard 62-89*, ASHRAE Journal, Sept. 1992.). In this system, the airflow offset between the supply and return fans must be made up by outside air. While that is true, there are flaws with this system as a ventilation control:

- The required outside airflow may exceed the offset chosen for proper building pressurization. Increasing the pressurization flow to match the outside air requirement may not be acceptable; for example, the doors could stand open.

- The method is inaccurate. The errors in each flow measurement add up in a way that makes the calculated difference very inaccurate. It may be close enough to meet pressurization requirements which are not very exact, but in some cases it is not close enough to regulate outside airflow as required (Kettler, Minimum Ventilation Control for VAV Systems: Fan Tracking vs. Workable Solutions, ASHRAE Transactions 1995).

Improved Method: Direct Measurement

The control engineer's approach to the problem of controlling an unknown quantity of outside air is to measure it and apply feedback to force it to the setpoint. **When practical, this is the preferred approach.** In many cases, it is impossible to install an accurate sensing system in the outside air intake at an affordable price. Challenges include low air velocities, wide range of weather conditions, and lack of straight flow. However, there are many products on the market aimed specifically at this need. Review your options and find the most cost effective approach. If it is early enough in the construction cycle, discuss the need for outside airflow sensing with the HVAC designer. That person may be able to design the intakes to accommodate a practical sensing arrangement. Table 2 lists some options. Any of these sensing methods can be applied to a fixed ventilation strategy or to a DCV system.

Table 2. Outside Airflow Measurement Products.

Manufacturer	Components
Siemens	When it is possible to get long straight outside air ducts (six duct diameters upstream and three duct diameters downstream of sensor installation) , the Siemens QVM62.1 duct air velocity sensor is an excellent way to calculate the outside air intake flow by multiplying the know cross-sectional area of the duct by the measured air velocity. See *Appendix B* for detailed specifications on this sensor.
Ebtron	Grid of electronic air velocity sensors. Designed for low velocity. May have a problem with temperature compensation.
Ruskin	Packaged outside air control system. Calibrated flow sensor in custom built damper. Includes damper motor and controller. Accepts variable outside airflow setpoint as an analog input. Complete outside air control package. Appears expensive when considered as a sensor or a damper. May be cost effective when viewed as a ventilation controller.
Trane	Outside air sensing station built into packaged air handlers. Forces the outside air through a parallel set of round sections with pitot type sensors. Looks like inlet to VAV boxes.
Miscellaneous	When it is possible to get long straight outside air ducts, many flow sensing systems work, including ordinary flow stations and differential pressure transmitters.

Improved Method: Plenum Pressure Control

It was stated earlier that varying suction pressure in the mixing plenum causes variations in outside airflow. **When it is not possible to directly measure the outside airflow (due, for example, to the lack of long, straight outside air ducts), the direct solution to the problem is to measure and control the plenum pressure.** The first step is to separate the outside air damper signal from the return air damper. With the outside air damper fixed at its minimum opening, the return air damper is modulated to regulate the suction pressure. As the supply flow decreases and the fan slows down, the suction in the mixing plenum is reduced. The outside airflow and the return airflow both decrease. The controller senses the reduced suction and adjusts the return damper a little farther closed. This increases the suction pressure, which pulls in more outside air. The outside airflow returns to the original level as the suction pressure settles in at setpoint.

The system must be calibrated during start-up. With an air balancer's readings, you can find the minimum outside air damper setting and the suction pressure that pulls the required outside airflow.

Unlike the systems direct measurement options, this system only works at the operating point where it is calibrated. Typically that is just at one outside airflow level. For the DCV application, the operation was extended to two outside airflow levels. The system is calibrated at the Minimum Ventilation Rate and at the Design Ventilation Rate.

For additional information, see the following:

- Kettler, J.P., *Minimum Ventilation Control for VAV systems: fan tracking vs. workable solutions*, ASHRAE Transactions, 1995.
- Mumma, S.A., *Analytical evaluation of outdoor airflow rate variation vs. supply airflow rate variation in variable air volume systems when the outdoor air damper position is fixed*, ASHRAE Transactions, 1990.

General Resources on IAQ, DCV and Their Relationship to LEED

Below are some additional Web links on the general topics of Indoor Air Quality, Demand Control Ventilation, and their relationship to the LEED 2009 Green Building Rating Systems:

- Strategies for Success in LEED Article 2: CO_2 Monitoring Advances Air Quality and Energy Efficiency (by Chris Schaffner)
- The Indoor Air Quality Guide: Best Practices for Design, Construction and Commissioning
- USGBC: LEED Rating Systems
- USGBC: LEED Reference Documents
- USGBC: LEED Version 3
- Demand Control Ventilation using CO_2 Sensors (Federal Technology Article Provided by the US Department of Energy Efficiency and Renewable Energy)
- LEED Case Studies (Includes detailed project information, contact information for project teams)

Chapter 2 – Concept and Sequence of Operation

Chapter 2 includes information specific to the ventilation control application presented in this guide. It tells how the application works and why it works that way. It includes information on the following topics:

- Description of the Ventilation for Acceptable Indoor Air Quality (VAIAQ) sequence
- Explanation of Ventilation for Acceptable Indoor Air Quality (VAIAQ) features
- Sequence of operation

Description of the Ventilation for Acceptable Indoor Air Quality (VAIAQ) Sequence

This example sequence is base on the sequence for an Air Handling Unit–VAV with Return Fan, Variable Frequency Drive on Each Fan, Chilled Water Cooling Coil, Hot Water Heating Coil. This sequence adds <u>four</u> VAIAQ features:

a. *Demand Controlled Ventilation* – Adjusts the outside air intake according to the actual (calculated) occupancy for the space.

b. *Improved minimum outside air control* – When outside air intake is at its fixed minimum value, the application controls it more reliably than the standard minimum damper setting.

c. *Fresh air purge before occupancy* – Runs outside air through the building before warm-up or cool-down to remove contaminants that accumulate while the system is off.

d. *Building pressure control* – Effective building pressurization is essential to effective outside air control and proper IAQ. This sequence ensures that the building is positively pressurized by running the supply fan at a greater speed than the return fan.

These features fit together and are applied here in one system. They are also independent and may be applied separately to meet the needs of a particular building. <u>Five</u> components are added to implement <u>three of the four</u> added features (see Figure 2):

1. *Minimum outside air damper* – Can be a separate damper admitting outside air to the mixing plenum, or it can be a separately operated section of the main outside air damper. This damper has its own two-position actuator and DO point.
2. *Main outside air damper* – This damper is not operated with the return and exhaust dampers and has a separate actuator and AO point.
3. *Space CO_2 sensor* – This sensor is an indicator of the actual ventilation rate per person. It should be placed in the occupied space.
4. *Outside air CO_2 sensor* – This sensor is best located near the outside air intake and may serve multiple air handlers.

5. *Mixing plenum pressure sensor* – A low range sensor that measures the difference between the static pressure in the mixing plenum and the outside air (the pressure drop across the outside air dampers).

The fourth feature, building pressurization control, does not require any additional components.

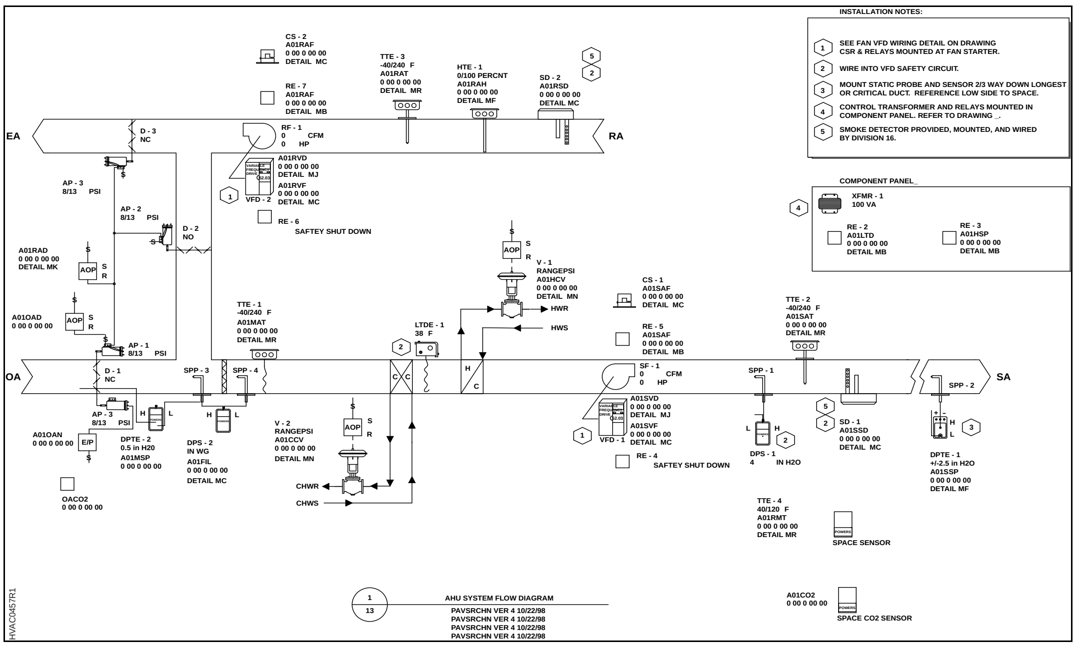

Figure 2. Mechanical Schematic.

Explanation of VAIAQ Features

The following sections explain the operation of the program features that are related to ventilation, outside airflow and building pressurization.

Minimum Ventilation

The minimum outside air damper combined with modulating the return and exhaust dampers provides minimum ventilation. When the system operates at minimum ventilation, the modulating outside air damper is closed and the minimum outside air damper is open.

The return and exhaust dampers modulate to hold the suction pressure in the mixing plenum at its fixed setpoint. With fixed pressure drop (between the outside and the mixing plenum) across a fixed opening (the minimum outside air damper) the outside airflow is controlled to a constant value.

If the VAV terminals begin to shut down, reducing the supply airflow, then the fan draws less outside air and less recirculated air, partially relieving the suction in the mixing plenum. The feedback loop senses the pressure change and closes down the return air damper, and opens the exhaust. The result is that the supply fan draws less return air, but maintains the same outside airflow.

When the modulating outside air damper begins to open (either for free cooling or for Demand Control Ventilation) the pressure controller continues to operate. This ensures that the outside airflow does not drop below the minimum.

Free Cooling

The modulating outside air damper provides free cooling the same way that a standard economizer program does it with the mixing dampers. If the supply air gets too warm, the modulating outside air damper opens to admit increased cool outside air. (This partly relieves the suction pressure in the mixing plenum, so the return air damper closes to restore it). The result is a cooler mix and cooler supply air. The override for a low mixed air temperature reading works exactly as in the standard program.

Demand Controlled Ventilation

The outside air damper modulates to deliver increased ventilation according to the occupancy, as indicated by the zone and outdoor air CO_2 sensors. The control program selects between the free cooling function and DCV by applying the larger of the two outside air damper commands. A table program that opens the OA damper when the zone CO_2 concentration increases implements the DCV ventilation reset function. In effect, this is proportional control. Proportional control is used because, unlike PI, it begins to adjust the outside airflow before the CO_2 concentration reaches the setpoint. This is desirable because of the way CO_2 concentration lags behind the actual occupancy.

In this sequence, DCV has been paired with plenum pressure control to regulate the outside airflow. It also works with direct sensing and control of outside airflow. For more information, see the *Introduction to IAQ and Ventilation Control* section in *Chapter 1*.

Building Pressurization

Effective building pressurization is essential to effective outside air control and proper IAQ. The direct effects of unwanted infiltration on IAQ are explained in *Chapter 1, Introduction to IAQ and Ventilation Control.* The issue here is even more basic: outside airflow cannot be regulated without accurate fan tracking. If the return fan flow is inadequate, air flows backward through the exhaust damper, adding to the outside airflow drawn through the intended opening. If the return fan flow is too great, it lowers the building pressure and draws outside air by infiltration. Either way, control of the actual outside airflow is lost and an energy penalty is paid.

In this sequence, building pressure is controlled by running the return fan at a speed of approximately 10% below that of the supply fan. Note that this will positively pressurize the building without flow stations or a building pressure sensor because that is the easiest method of building pressure control. The ventilation control features described here can be implemented just as well with the other building pressure control methods.

The building pressurization function is very similar to standard programs. The return fan speed is calculated from the supply fan speed. This sequence uses a variable ration, instead of a constant ratio. This makes it possible to more accurately match the fan signals on the job site. This sequence calls for a table to be set up that matches certain supply fan speed with corresponding return fan speeds. The table must be adjusted on the job site to match the characteristics of the equipment. Use as many pairs of values as necessary to accurately pressurize the building throughout the operating range.

Purge

The fresh air purge cycle can run at two different outside airflow rates. In mild weather, the purge runs at the Design Ventilation Rate. In extreme (hot or cold) weather, it runs at the Minimum Ventilation Rate. It controls the ventilation rate by the same mechanism used in the occupied mode: fixed outside air damper position with plenum pressure control.

The sequence starts when the equipment scheduler turns on the Purge. If the outside air temperature is outside selected limits, the purge begins immediately at the Minimum Ventilation Rate. If the outside air temperature is between the limits, purge runs at the higher outside airflow rate and starts later. The delay is implemented in the program.

The sequence is designed to deliver fresh air without changing the space temperature. This means purge does not disturb the work of the warm-up or cooldown mode. Purge can run before or after the warmup/cooldown. In some cases (warmup needed, cold outside), purge will consume more energy if it runs first. In other cases (cooldown needed, cold outside), purge will consume less energy if it runs first.

The fresh air purge will not improve IAQ if it introduces excess humidity to the space. The purge mode uses a humidity override to avoid that problem. As in the occupied mode, if the space humidity rises too far, the cooling coil gives up temperature control, and begins to dehumidify. To emphasize dehumidification during purge, a two-position control is applied. A dead band switch opens the coil all the way when the humidity exceeds a critical level. When the humidity drops below the deadband, cooling control resumes. In very humid climates, it may be more effective to respond to the dew point in the outside air or the supply air rather than controlling according to humidity in the space.

Sequence of Operation

The air handling unit consists of a mixed air section with a minimum outdoor air damper, a modulating outdoor air damper, an exhaust air damper and a return air damper, pre-filter, chilled water cooling coil, hot water heating coil and supply and return fans with individual variable frequency drives. The unit is DDC controlled.

The air handling unit is scheduled for automatic operation on a time of day basis for Occupied, Unoccupied and Purge modes. Within the Occupied mode, the system can enter the Warm-Up mode when the space temperature is below setpoint or the Cool-Down mode when the space temperature is above setpoint. The system stays in the Warm-Up or Cool-Down mode until the mode setpoint is satisfied or until the scheduled occupancy time is reached. Purge mode occurs before the Occupied mode. Within the Unoccupied mode, Night Heating is available when the space temperature drops below 65°F (18°C) and Night Cooling is available when the space temperature rises above 85°F (29°C).

The air handling unit operates in Warm-Up, Cool-Down, Purge, Occupied, Unoccupied, Night Heating, Night Cooling and Safety modes as follows.

All suggested setpoints and settings are adjustable.

- *Warm-Up* – The supply and return fans start. The mixing dampers position for 100% return air and the cooling coil valve remains closed. The heating coil valve modulates to maintain the discharge temperature at setpoint. The system is prevented from entering the Warm-Up mode more than once per day.

- *Cool-Down* – The supply and return fans start. The heating coil valve, mixing dampers and cooling coil valve modulate in sequence without overlap to maintain the discharge temperature setpoint. Return air humidity overrides control of the cooling coil valve to maintain 55% relative humidity. When the outside air dry bulb temperature is above the economizer changeover value, the mixing dampers are positioned for 100% return air. The system is prevented from entering the Cool-Down mode more than once per day.
- *Purge* – The supply and return fans start or continue to run, and the minimum outdoor air damper opens. If the outdoor temperature is in a selected range, the modulating outdoor damper opens to the position that corresponds to the Design Ventilation Rate. The return air damper modulates to control the suction pressure in the mixing plenum. The heating coil valve and cooling coil valve modulate in sequence without overlap to maintain the discharge temperature at the value of space temperature sampled before the mode begins. Return air humidity overrides control of the cooling coil valve to dehumidify the incoming air.
- *Occupied* – The fans start or continue to run and the minimum outdoor air damper opens. The heating coil valve, modulating outdoor air damper and cooling coil valve modulate in sequence without overlap to maintain the discharge temperature setpoint. Return air humidity overrides control of the cooling coil valve to maintain 55% relative humidity. The modulating outdoor damper ramps open slowly on start-up to minimize overshooting.

  The return air damper (operated with the exhaust air damper) modulates to control the suction pressure in the mixed air plenum. This regulates the flow of outdoor air. The return air damper ramps closed slowly on start-up to minimize overshooting.

  When the outdoor air dry bulb temperature is above the economizer changeover value, the modulating outdoor air damper closes; the minimum outdoor damper remains open. Below this temperature, the mixing dampers modulate with the heating coil and cooling coil valves to maintain the discharge air temperature setpoint with a low limit of 48°F (9°C) at the mixed air sensor.

  As the carbon dioxide concentration in the space rises, the outside air damper modulates open to maintain the desired ventilation rate per person. In selecting between free cooling and DCV, the function with the greater need for outside air takes control of the damper.
- *Unoccupied (Normal Off)*– The fans are off, the cooling coil and heating coil valves close and the mixing dampers close to the outdoor air.
- *Night Heating* – The supply and return fans start with the heating coil valve open to maintain a minimum space temperature of 65°F (18°C). The cooling coil valve remains closed and the mixing dampers remain closed to the outdoor air.
- *Night Cooling* – The supply and return fans start and the cooling valve and mixing dampers are modulated to maintain the supply setpoint temperature. Return air humidity can override the cooling valve to maintain the humidity setpoint. The heating coil valve remains closed.

- *Supply Duct and Building Pressurization Control* – The supply fan variable frequency drive modulates to maintain a constant duct static pressure of 1.5 inches of water as sensed at least two-thirds of the way downstream of the supply fan in the longest or most critical duct. The return fan variable frequency drive is operated at a speed that corresponds to approximately 10% less than supply fan speed, and is selected to correctly pressurize the building. Upon initial startup of the air handling system, the supply and return fan speed slowly ramps to the desired static pressure setpoint. Upon shutdown of the air handling system, the supply and return fan variable frequency drives stop and the speed reset signal goes to zero speed.
- *Safety* – Discharge high static cutout, smoke detectors in the supply and return air streams, and supply and return fan VFD fault alarms de-energize the supply and return fans upon activation. A low temperature detector in the mixed air stream de-energizes the supply and return fans when temperatures below 38°F (3°C) are sensed. All dampers and valves position to their normal position after the fans are de-energized.

  Current switches are installed in the power feed line to the supply and return fan VFDs. The DDC system uses the switches to confirm that the fans are in the desired state (that is, on or off) and generates an alarm if the status deviates from DDC start/stop control. The DDC system generates a VFD trouble alarm independent from the fan status.

Zone Control Application for DCV

The following is an example of a sequence that provides zone-level DCV for a VAV terminal box with heating and cooling coils. The difference between the outside air and zone CO_2 levels (differential CO_2) is used in a control loop to override the normal temperature-driven signal of the VAV box damper to provide the proper ventilation requirement, as determined by the differential CO_2 setpoint.

In this sequence, the CO_2 differential setpoint for each zone should be calculated in the custom program using Equation (4) in this guide, with the P_z (zone population) variable in this equation calculated according to Equation (3) in this guide. Total ventilation requirement at the AHU") is calculated in the program as the sum of the ventilation requirement for all of the spaces. The space ventilation requirements for each zone are determined by the number of people in each zone, calculated in the program.

Description of Zone Control Application for DCV

The zone application for DCV is a VAV controller used for temperature and ventilation control. This application is suitable for conventional VAV as well as chilled beam applications. In the cooling mode, the airflow and a chilled water valve can be modulated in series, in parallel or overlapped. If the VAV box airflow is to be modulated in heating mode, the airflow and the heating valve can be modulated in series, in parallel or overlapped. The heating coil and cooling coil valves can each be independently configured to be either floating control or analog control. This application also includes a Demand Control Ventilation (DCV) sequence that monitors CO_2 levels within the space. If additional ventilation is required based on CO_2 levels, the temperature control damper position is temporarily overridden to a new position that assures adequate ventilation. While in the ventilation mode, the temperature control is maintained via the heating and/or cooling coils.

Figure 3 illustrates the control drawing for Zone Control Application for DCV,

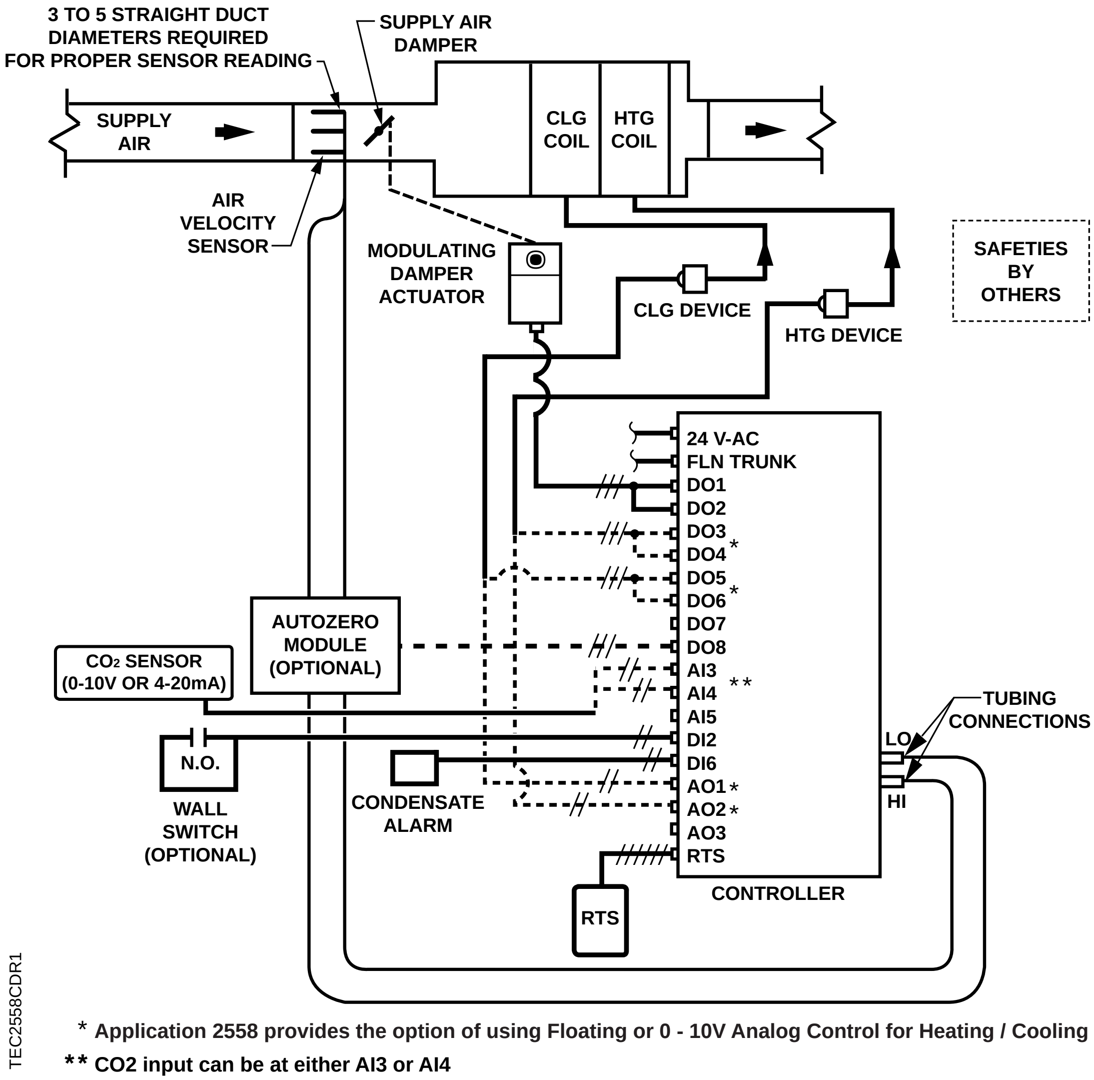

Figure 3: Control Drawing for TEC Application 2558 and PTEC Application 6658.

Ventilation Control

With a known ventilation rate and number of occupants, a predictable steady state concentration of CO_2 can be maintained. DCV uses this principle to modulate ventilation to acceptable levels based on CO_2 concentrations within the space. Rather than having a minimum ventilation based on full occupancy of a space, DCV allows ventilation airflow to be modulated below what otherwise would be the full occupancy ventilation minimum, provided that the CO_2 concentration (in ppm) indicates adequate ventilation.

CO_2 (Ventilation) Loop

In Ventilation mode the damper is no longer controlled by the temperature loops. Instead, the damper is modulated to assure adequate ventilation.

CO2 DIFFERENTIAL SETPOINT is the desired CO_2 concentration differential between ROOM CO2 and OUTDOOR CO2.

If zone-level DCV is being used, CO_2 differential setpoint must be calculated according to Equation (4).

CO_2 differential is the measured CO_2 concentration differential between the ROOM CO2 and OUTDOOR CO2, and serves as the input to the CO_2 (ventilation) loop. The OUTDOOR CO2 would typically be a value shared from a single-source outdoor air CO_2 sensor wired to any field panel.

The CO_2 loop brings the measured CO_2 differential to the desired CO_2 differential setpoint by adjusting the damper position. When the damper is being modulated during ventilation mode, temperature control is maintained by modulating the chilled water and/or hot water valves.

Determining the Zone Population

Occupancy is calculated using the following equation from Ke and Mumma (1997)28. Use Equation (3) to calculate the P_z term in Equation (4) to define dynamic values of the zone CO_2 setpoint as the zone population varies.

$$P(t) = \frac{v\frac{C(t) - C(t-\Delta t)}{\Delta t} + Q_s(t)\left[C(t) - C_s(t)\right]}{G \times 1{,}000{,}000} \qquad \textbf{(3)}$$

Where:

- $P(t)$ = number of people in the zone
- v = zone volume, ft^3
- $C(t)$ = zone CO_2 concentration, ppm
- $C(t\text{-}\Delta t)$ = zone CO_2 concentration one time step back, ppm
- Δt = the time step in minutes. The recommended time step can vary between one (1) and five (5) minutes.
- Q_s = supply airflow to the zone, cfm
- $C_s(t)$ = CO_2 concentration of supply air, ppm (if not measured, then assume to be 200ppm higher than the OUTDOOR CO2)
- G = the CO_2 generation rate per person, cfm

Determining the Zone Differential CO_2 Setpoint

The difference between the OUTDOOR CO2 and ROOM CO_2 levels is called the CO2 differential setpoint.

The steady-state differential CO_2 concentration for a zone can be calculated by the following Equation (4)[29]:

[28] Ke, Yu-Pei and Mumma, Stanley A., Using Carbon Dioxide Measurements to Determine Occupancy for Ventilation Controls, ASHRAE Transactions, V103(2), pp. 365-374, 1997.

$$C_R - C_{OA} = \frac{8400 E_z m}{R_p + \dfrac{R_a A_z}{P_z}} \qquad \textbf{(4)}$$

Where:

- the factors R_p, R_a, A_z and P_z are defined as in Equation 6-1. R_p and R_a are given in Table 6-1 of ASHRAE Standard 62.1-2010.
- C_R = zone CO_2 concentration (ppm)
- C_{OA} = Outside air CO_2 concentration (ppm)
- E_z = zone air distribution effectiveness (a value ranging from 0.5 to 1.0 from Table 6-2 of ASHRAE Standard 62.1-2010)
- m = Activity level of people in zone (met)
- R_p = People component of ventilation rate required (cfm/person, L/s/person). From Table 6-1, ASHRAE Standard 62.1-2010.
- R_a = Zone area component of ventilation rate required to vent effluents (out gassing) from carpeting, furniture, paints, etc. (cfm/ft^2, L/s/m^2). From Table 6-1, ASHRAE Standard 62.1-2010.
- A_z = Zone floor area (ft^2, m^2)
- P_z = Current number of people in zone

Note that in Equation (4), as the zone population (P_z) increases, the zone CO_2 differential setpoint increases, and as the zone population (P_z) decreases, the zone CO_2 differential setpoint decreases. This means that the zone CO_2 differential setpoint changes as the zone population changes and one cannot simply control the zone differential CO_2 setpoint at a constant value to meet the ventilation requirements of ASHRAE Standard 62.1.

[29] Taylor, Steven T., Chicago ASHRAE Winter Meeting, January 2009,Seminar 22, DVD Recording #4562_2, Taylor Engineering, Alameda, CA. This equation also appears in the User's Manual for ASHRAE Standard 62.1-2010 in Appendix A as Equation (A-J).

Chapter 3 – Designing a Central DCV System

Chapter 3 describes the tasks carried out by the HVAC controls design (consulting) engineer applying this system and includes the following topics:

- Setting outside airflow levels
- Designing minimum outside air control
- Setting purge control points
- Coordinating terminal controls with the air handler
- Determining outside CO_2
- Locating space CO_2 sensors
- Setting Demand Controlled Ventilation (DCV) control points

Setting Outside Airflow Levels

When setting outside airflow levels the first thing to find out is who will set the ventilation rates. This could be done by a representative of the building owner or by an HVAC designer. The person who sets the values is the one who will take responsibility for the IAQ aspects of ventilation. The following values are required when setting outside airflow levels:

- *Exhaust and Exfiltration Rate* – the flow required to pressurize the building
- *Design Ventilation Rate* – the flow required at full occupancy
- *Minimum Ventilation Rate* – the “floor area” component of the ventilation requirement during “occupied hours”, according to Equation (1) of this document (Eq 6-1 in ASHRAE 62.1-2010). (It is assumed the ventilation system is turned OFF during “unoccupied hours”.)

If the outside airflow required for make-up air volume exceeds that needed for ventilation, then the space will be over-ventilated. This may happen at low population levels. Since the ventilation requirement can change as occupants come and go, a building may have outside airflow requirements that are set sometimes by ventilation and other times by make-up air. The highest of these values is the outside airflow setpoint.

After the appropriate ventilation rates are selected, it is necessary to verify that the HVAC equipment can handle the load. Enhanced ventilation controls can increase or decrease the amount of outside air intake depending on the system and the operating condition. Evaluate the system at the new operating conditions from the perspective of an HVAC engineer. Issues include the following:

- *Heating capacity* – The heating coil has to handle the Design Ventilation Rate at any expected outside air temperature.

- *Cooling capacity* – Usually not a problem because cooling systems are expected to operate at the Design Ventilation Rate on hot days.
- *Dehumidification capacity* – Maximum dehumidification load may not coincide with maximum cooling.
- *Freeze protection* – Many existing systems under-ventilate at low loads and upgrading them can create very cold mixed air. Analyze the situation to decide how to prevent the freezing coils from tripping the freeze stat. Options include keeping the coil flowing at all times, ensuring adequate return air is mixed with the outside air, adding glycol to the system, add a preheat coil, etc.
- *Exhaust capacity* – Make sure you have the equipment to remove all the air that you bring in.
- *Damper sizes* – The minimum outside air damper must admit the minimum ventilation flow at a pressure drop of about 0.2 inches. The return air damper must be tight enough that leakage flow won't defeat the outside air control.

CAUTION:

While ventilation is extremely important, it may be better to reduce the quantity of outside air at extreme operating conditions, than to fail to condition it properly. Some DCV control sequences automatically override the ventilation to lower when the load exceeds the capacity of the equipment. Some do not. As the "engineer of record", you must decide which function should take priority – conditioned air or level of ventilation.

Required Measurement of Outside Airflow

If your building codes for fresh air ventilation comply with *ASHRAE Standard 62.1-2010*, and the supply air handler fan is a VAV unit, be aware that direct measurement of outside air intake is required for each outside air duct supplying fresh air to zones that will be demand control ventilated[30]. It is recommended that an air velocity sensor be installed in the outside air duct for all AHU's serving those zones to be demand control ventilated and multiplying this reading by the cross-sectional area of the duct to calculate the actual outside airflow in cfm.

It is not recommended that a differential pressure airflow measuring station be used to measure the outside air intake – they exhibit large error at low flow conditions. Instead, calculate outside airflow by using a duct air velocity sensor reading (a device using hot-wire anemometer technology) multiplied by the duct cross-sectional area. Compared to air measuring stations, air velocity sensors are much less expensive and exhibit good accuracies at low flow conditions.

[30] Direct measurement of outdoor airflow may not be necessary if the supply air handler fan is a constant-speed device. In this case, ASHRAE Standard 62.1 ventilation requirements can be met if an outside air **modulating** damper is provided, and the controls for it are properly setup. See section on how this might be done.

In addition, if your building owner is contemplating a green building certification from LEED (Leadership in Energy and Environmental Design), be aware that the *LEED 2009 Green Building Operations and Maintenance* rating system (for existing buildings), Indoor Environmental Quality Credit 1.2 (1 Point), also requires the installation of permanent monitoring systems to provide feedback on ventilation system performance to ensure ventilation systems maintain minimum outdoor airflow rates under all operating conditions. For mechanical ventilation systems that predominantly serve densely occupied spaces[31], a CO_2 sensor is required to be installed in each densely occupied space and compared to a measurement of the outdoor ambient air CO_2 concentration.

Designing Minimum Outside Air Control

The sequence uses the plenum pressure control method to regulate OA flow. Note that the plenum pressure control method of regulating the OA flow should be used when OA duct design considerations preclude the use of directly measuring OA flow from duct air velocity sensing (see the *Improved Method: Plenum Pressure Control* section).The concept is described in *Introduction to IAQ and Ventilation Control* in *Chapter 1*. The following list describes the design steps:

1. Select and locate a plenum pressure sensor. You don't want flow directly at or away from the inlet to the sensor. Consider using a static pressure probe.
2. Use a two-position actuator for the minimum outside air damper.
3. Check the minimum outside air damper size.
4. Check the return damper size and leakage.

The HVAC engineer should determine the size of the minimum outside air damper. If it is a portion of the main damper, then the engineer decides what part of the outside air damper to use for the minimum opening. Typically, the outside air dampers are sized at one square foot for every 500 to 1,000 cfm. In this application, the higher end of that velocity range is appropriate in order to maintain a significant pressure drop.

The HVAC engineer must also size the return air damper carefully. (In the case of a retrofit job, check the size and consider blanking off a portion of the damper). The damper has to be large enough to pass the maximum return flow (maximum supply flow minus the Design Ventilation Rate) at a pressure drop of a few tenths (0.3 to 0.5 inches). However, a damper that is too large is more of a problem than a damper that is too small. A damper that is too large or too leaky won't close down tight enough to properly control the outside airflow.

Setting Purge Control Points

When setting the purge control points, first select the duration of the purge cycle according to Equation (2).

[31] *ASHRAE Standard 62.1-2010* and the *LEED 2009 Operations and Maintenance* and *LEED 2009 Design and Construction* green building rating systems define densely occupied spaces as those with a design occupancy density of 25 people or more per 1000 square feet (less than 40 square feet per person).

Next, decide the daily sequence of the modes. If the system runs warm-up or cool-down modes, purge may run before or after. There are energy and air conditioning implications of the sequence that vary from system to system.

Finally, determine the outside air temperature limits where the system does not need to condition the outside air. If humidity is a concern, factor in a high humidity limit. In these conditions, the purge can run with 100% outside air and for a short time.

In the winter, the purge mode heats the fresh air to the space temperature. Control the heating coil so that the discharge air is heated to the space temperature. In this condition, the outside air intake should be set to a minimum and run for a longer period of time.

In the summer, the purge mode cools the fresh air and dehumidifies if necessary. Control the cooling coil so that the discharge air is cooled to the space temperature. If the outside air is above a humidity high limit, then run the dehumidification sequence to provide cool dry air. In this condition, the outside air intake should be set to a minimum and run for a longer period of time.

Coordinating Terminal Controls with the Air Handler

The complete ventilation control job requires control at the VAV terminals to work with the sequence at the air handler. Ventilation is not just pulling outside air into the air handler, it means delivering it to the people in the spaces. Specific coordinated actions include:

- **Set the supply flow at least as great as the required outside air.** The terminals determine the supply airflow (the air handler controls cannot do this). The air handler controls mix the required quantity of outside airflow into the supply, but only if the supply is great enough. If the supply flow is less than the required outside airflow, the system under-ventilates the space. In every mode, make sure that the terminals call for enough air to accomplish the ventilation. This means setting heating minimums, cooling minimums, and making sure the boxes call for flow during the purge sequence.
- **Distribute the air as required through the occupied space.** Consider the possibility that one zone has the critical need for ventilation (a crowded room) but doesn't get a large amount of supply air (maybe because of a large cold exposure). It may be appropriate to raise the minimum flow or to implement zone level DCV for that zone, which would adjust the flow through the terminal in response to occupants.
- **Set the supply flow high enough to generate the desired mixed air conditions.** Freeze protection for the coils can depend on mixing cold outside air with return air. If this is the case, make sure the return air is there. The outside air quantity is set by the air handler control system and the supply air quantity is set by the terminals. The return air quantity is the difference. Set up the terminals to use enough supply flow that there will be enough return air in the mix.

Determining VAV Box Minimum Settings

For DOAS supply, the box minimums should match the ventilation minimums. If DCV is applied to the zone, then the box minimum can vary based on the occupancy. The ventilation flow to one zone does not affect the flow to the other zones. Since the primary outside fraction (Z_{pz}) is always 1.0 for a DOAS system, the flow to the space can always match the ventilation minimum, unless there are other parameters that might increase the airflow to meet environmental setpoints.

For MA AHU systems, the primary outdoor air fraction (Z_{pz}) has a large effect on the outdoor air that has to be drawn in at the AHU. The outdoor air intake airflow setpoint is calculated based on the worst case zone OA fraction. If one zone has a very high fraction (close to 1.0), then the AHU has to intake a high percentage of outdoor air to meet the need of that one zone. In a MA system, that means that all of the other zones will be substantially over-ventilated.

The other extreme is to minimize the outdoor air fraction for every zone (for example, .15), but that drives up the fan energy because it is re-circulating a lot of air.

The ideal situation is to keep the outdoor air fraction for every zone as close in range as possible without driving up the fan energy use on re-circulating air. For a mixed air system, a reasonable range for the primary outdoor air fraction (Z_{pz}) is 0.3 to 0.5. This range encourages the VAV boxes to run low enough minimums such that reheat will not be needed often, and provides enough mixing of outdoor air such that high occupancy spaces can be ventilated efficiently.

Note that if all spaces could be run at primary outdoor air fractions (Z_{pz}) above 0.5, then the AHU will always be running at an intake percentage of 50% or above. It would be wise for the engineer to consider a DOAS system for ventilation and supplemental cooling for the spaces.

If all spaces run at primary outdoor air fractions (Z_{pz}) less than 0.3, then all are at a risk of needing reheat when the load is low and forces the supply fan to re-circulate a lot of unnecessary air.

Determining Outside Air CO_2

The DCV application controls according to the difference between the CO_2 inside and outside. Because CO_2 is not sensed or controlled as an air contaminant, it is used as an indicator of the ventilation rate. *Chapter 1, Introduction to IAQ and Ventilation Control* explains this use of CO_2 as a tracer gas.

One outside air CO_2 sensor is enough for any number of systems in a building. In some locations, the CO_2 concentration is stable enough that it can be entered as a constant in the program, rather than measured. If a constant is used, it must be at the low end of the range of values expected for the location. Use 400 ppm as the general outside air CO_2 concentration level if no other (local) concentration is available.

Outdoor CO_2 concentration should be measured near the outside air intake, but preferably not near building exhaust. It also helps not to place the sensor where it will be directly affected by combustion, like in a parking garage, above a busy intersection, or near chimneys.

Locating Zone CO_2 Sensors

The location of the zone CO_2 sensor affects the operation of a DCV system in the same way that the thermostat location affects a temperature control system. The following sections summarize issues that affect sensor location.

CO_2-based DCV: Duct Versus Wall-Mounted CO_2 Sensors

Generally, it is recommended that sensors be installed in the occupied space rather than in ductwork (Schell and Int-Hout, 2001)[32]. This is because return air tends to be an average of all spaces being conditioned and may not be representative of what is actually happening in a particular space. Duct sensors are best used where a single space or multiple spaces with common occupancy patterns are being ventilated. The most common areas for installation are directly in the return air ductwork or inside the return air plenum just before it enters the air handler. For systems with return air plenums (rather than ductwork), leakage of outdoor air through the building envelope or from supply air ducts traveling through the plenum, may affect readings. In this case, sensors should be located in the space or where leakage is not a factor.

Location of Wall-Mounted CO_2 Sensors

Criteria for placement of wall-mount sensors are similar to those for temperature sensors (Schell and Int-Hout, 2001)[33]. CO_2 sensors should be installed in the breathing zone of a space. [*ASHRAE Standard 62.1-2010* defines breathing zone as “the region within an occupied space between 3 and 72 inches (75 and 1800 mm) above the floor and more than 2 feet (600 mm) from the walls or fixed air conditioning equipment.” *LEED 2009 Green Building Operations and Maintenance* defines the breathing zone as being between 3 and 6 feet above the floor.] Avoid installing CO_2 sensors in areas near doors, air intakes or exhausts or open windows. Because people breathing on the sensor can affect the reading, find a location where it is unlikely that people will be standing in close proximity (2 ft [0.6 m]) to the sensor. One sensor should be placed in each zone where occupancy is expected to vary. Sensors can be designed to operate with VAV-based zones or to control larger areas up to 5,000 ft2 (465 m2) (if an open space).

One Sensor vs. Multiple Sensors

Depending on how the space is laid out, and how it is occupied, the CO_2 concentration may be nearly uniform, or it may vary significantly from one spot to another. If the concentration of CO_2 is uniform, one sensor will be enough. Place the sensor in the occupied space, at least several feet away from a spot where people will be breathing. If the CO_2 concentration varies, you can either choose one spot for a sensor, or you can apply multiple sensors. The best approach depends on the building.

If the space is one large room and people are spread out through it, then one CO_2 sensor is likely to give a good reading. Examples of this kind of space include auditoriums or theaters, open plan office areas, and single classrooms. Even in these cases, the sensor should be located away from a center of concentrated activity. If several sensors are used to get a better sample of the space, it is reasonable to average the readings and run the central DCV system according to the average.

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[32] Schell, Mike and In-Hout, Dan. 2001. Demand Control Ventilation Using CO_2. *ASHRAE Journal*, February.

[33] Ibid.

If the space is broken up into separate rooms and occupancy is likely to vary from room to room, then multiple sensors may be required. Examples of this kind of space include rows of private offices and multiple classrooms with different schedules. In this case the variations in readings represent actual variations in air quality. The central DCV system uses the CO_2 reading from the worst case zone to set the outside airflow rate.

Recommended Zone CO_2 Sensor

Siemens Series 2200 CO_2 “Three-in-One” sensing room units for BACnet PTECs provide accurate measurement of carbon dioxide, temperature, and relative humidity. This digitally-communicating device is compatible with all BACnet programmable Terminal Equipment Controllers and can measure all three metrics for monitoring and controlling down to the zone level.

Other benefits include:

- The appearance of units mounted side-by-side is eliminated with three elements in one housing.
- Product costs of extra devices and wall plates are eliminated.
- Extra labor costs per installation are eliminated.
- The unit has configurable display parameters to meet user preferences.
- The “full-featured three-in-one model” also has temperature setpoint adjustment and occupancy override/night setback commanding.
- Multiple Analog Inputs on the controller are freed up as a result of not having to terminate separate analog inputs for separately measured variables.

The Series 2200 CO_2 sensing room units are powered by a separate power module, the AQM2200. This device provides the extra power needed to run the CO_2 sensing element in the room unit. The CO_2 power module runs off of 24 Vac, and may be powered off of the same transformer that provides power to the PTEC. The CO_2 module may be mounted next to the PTEC on the terminal box, and easily connects in line between the PTEC and the room unit, using standard TEC cables. The AQM2200 must be ordered separately and installed with the Series 2200 CO_2 room unit; otherwise the unit will not work. More information about the CO_2 power module is located in the technical specification sheet and CO_2 Power Module installation instructions.

Carbon Dioxide calibration for the Three-in-one Unit is not necessary. The sensor allows the displayed and communicated value to be biased to ±50 PPM of the CO_2 reading. This reconciles the accuracy of the unit to a calibrated handheld device. The range of the CO_2 digital sensor IC is 0 to 2000 PPM and accuracy is ±50 PPM + 2% of reading. The temperature operating range of the unit is 55°F to 95°F (13°C to 35°C) and accuracy is ±0.9°F (±0.5°C). The humidity range of the unit is 0% to 100% rh and accuracy is ± 2% rh for 10% - 90% rh range or ± 4% rh for the extremes < 10% rh and > 90% rh.

The “Three-in-One” sensor is compatible only with Siemens BACnet PTEC’s. Existing sites that do not use Siemens BACnet PTECs for their terminal equipment controllers can use different CO_2 sensors or upgrade to take advantage of using the Three-in-one Sensor.

Setting DCV Control Points

The DCV ventilation reset algorithm needs the following four values to specify the operation of the algorithm:

- **High value of outside air damper opening** – select this value on the job site, with the system running, and the air balancer available to verify that the outside airflow meets the Design Ventilation Rate.
- **Low value of outside air damper opening** – set this value to zero if there is a separate, two-position actuator to give the minimum required damper opening. If not, then the damper setting will be adjusted to draw the Minimum Ventilation Rate. This adjustment is described in *Implementing, Troubleshooting and Maintaining a Central DCV System* in *Chapter 4.*
- **Low value of CO_2 rise** – set this value to zero.
- **High value of CO_2 rise** – calculate the CO_2 rise expected with the system at full occupancy and ventilated according to the specification. The following paragraph explains how to set the high CO_2 value for the sequence.

The increased CO_2 concentration above the level in the outside air depends on the ventilation rate and the rate that the people generate CO_2. People generate CO_2 at a rate that increases with the size of their body and their activity level. Table 3 shows accepted steady-state CO_2 concentration and CO_2 rise values that were calculated from Equation (4) in Chapter 2 (assuming the “people component” of the ventilation rate (cfm/person or liters/sec per person) and the occupant density (number of people per 1000 ft^2 or m^2) are as specified in Table 6-1 of ASHRAE Standard 62.1-2010) for some DCV applications and gives the corresponding value for use in the DCV program. For any unusual use of the space, or any other justifiable ventilation rate or occupancy density, the value P_z must be calculated using Equation (3).

Consult with your Siemens representative if questions persist on how to determine zone CO_2 setpoints.

Table 3. Accepted Values for DCV Applications.

Type Occupancy	Activity Level (MET)	Steady-state Zone CO_2 Concentration	CO_2 Rise (ppm)[34]
Office space	1.2	990	590
Classrooms (age 9+)	1.0	1,025	725
Restaurant dining rooms	1.4	1,570	1,170
Conferences/ Meeting spaces	1.0	1,755	1,355
Lobbies/Prefunction	1.5	1,725	1,325
Sales	1.5	1,210	810

[34] Based on a constant 400 ppm outdoor air CO_2 concentration.

Calculating Zone Ventilation Requirements

The sequence is built around an example of a single-duct, two-zone system, with a variable-speed fan in both the supply and return air ducts, and is based on maintaining breathing zone ventilation requirements as specified in Equation 6-1 of *ASHRAE Standard 62.1-2010* when the number of occupants in a zone is dynamically changing.

$$V_{bz} = R_p \cdot P_z + R_a \cdot A_z \tag{6-1}$$

[ASHRAE Standard 62.1-2010]

Where:

V_{bz} = the breathing zone outdoor airflow, cfm (L/s)

R_p = Outdoor airflow rate (cfm, L/s) required per person as determined from Table 6-1 in ASHRAE Standard 62.1-2010.

Note: The following values are based on adapted occupants.

P_z = zone population: the number of people in the *ventilation zone* during typical usage. Default values of occupancy density (number of people per 1000 ft^2 or m^2) are defined in Table 6-1 of ASHRAE Standard 62.1-2010.

R_a = outdoor airflow rate (cfm, L/s) required per unit floor area (ft^2, m^2) as determined from Table 6-1 in ASHRAE Standard 62.1-2010.

A_z = zone floor area: the net occupiable floor area of the zone, m^2 (ft^2).

Where:

the zone population, P_z in Equation 6-1 can be determined as $P(t)$ from (3)[35]:

Section 6.2.2.3 of ASHRAE Standard 62.1-2010 defines the outdoor air that must be maintained in each zone:

Section 6.2.2.3 Zone Outdoor Airflow

The desired zone outdoor airflow (V_{oz}), that is, the outdoor airflow rate that must be provided to the *ventilation zone* by the supply air distribution system, shall be determined in accordance with Equation 6-2.

$$V_{oz} = \frac{V_{bz}}{E_z} \tag{6-2}$$

[ASHRAE Standard 62.1-2010]

[35] Mumma, Stanley A. and Ke, Yu-Pei. 1997. Using carbon dioxide measurements to determine occupancy for ventilation controls. *ASHRAE Transactions*, 103(2).

Where:

E_z is the zone air distribution effectiveness and is determined by from Table 6-2 in the standard.

DCV can be applied to the following three cases as specified in *ASHRAE Standard 62.1-2010*:

Section 6.2.3 Single-zone Systems

For ventilation systems wherein one or more air handlers supply a mixture of outdoor air and recirculated air to only one ventilation zone, the outdoor air intake flow (V_{ot}) shall be determined in accordance with Equation 6-3.

$$V_{ot} = V_{oz} \tag{6-3}$$

Section 6.2.4 100% Outdoor Air Systems

For ventilation systems wherein one or more air handlers supply only outdoor air to one or more ventilation zones, the outdoor air intake flow (V_{ot}) shall be determined in accordance with Equation 6-4.

$$V_{ot} = \sum_{all\ zones} V_{oz} \tag{6-4}$$

Section 6.2.5 Multiple-Zone Re-circulating Systems

For ventilation systems wherein one or more air handlers supply a mixture of *outdoor air* and *recirculated air* to more than one *ventilation zone*, the outdoor air intake flow (V_{ot}) shall be determined in accordance with Sections 6.2.5.1 through 6.2.5.4.

Section 6.2.5.1 Primary Outdoor Air Fraction

The zone primary outdoor air fraction (Z_{pz}) shall be determined for *ventilation zones* in accordance with Equation 6-5.

$$Z_{pz} = \frac{V_{oz}}{V_{pz}} \tag{6-5}$$

Where:

V_{oz} is the desired zone outdoor airflow,

V_{pz} is the zone primary airflow, that is, the measured primary airflow rate to the *ventilation zone* from the air handler, and

V_{oz} is determined by Equation 6-2.

$$V_{oz} = \frac{V_{bz}}{E_z} \tag{6-2}$$

Where:

E_z is the zone air distribution effectiveness and is determined by from Table 6-2 in the standard, and

V_{bz} is determined from Equation (1) of this document (Eq 6-1 in ASHRAE 62.1-2010).

Section 6.2.5.2 System Ventilation Efficiency

The system ventilation efficiency (E_v) shall be determined in accordance with Table 6-3 or Normative Appendix A in ASHRAE Standard 62.1-2010.

Section 6.2.5.3 Uncorrected Outdoor Air Intake

The uncorrected outdoor air intake (V_{ou}) flow shall be determined in accordance with Equation 6-6.

$$V_{ou} = D \sum_{all\ zones} (R_p \cdot P_z) + \sum_{all\ zones} (R_a \cdot A_z) \tag{6-6}$$

Section 6.2.5.3.1 Diversity

The occupant diversity ratio (D) shall be determined in accordance with Equation 6-7 to account for variations in population within the *ventilation zones* served by the system,

$$D = \frac{P_s}{\sum_{all\ zones} P_z} \tag{6-7}$$

where the system population (P_s) is the total population in the area served by the system.

Exception: Alternative methods to account for occupant diversity shall be permitted, provided that the resulting V_{ou} value is no less than that determined using Equation 6-6.

The uncorrected outdoor air intake (V_{ou}) is adjusted for occupant diversity, but is not corrected for system ventilation efficiency.

Section 6.2.5.3.2 Design System Population

Design system population (P_s) shall equal the largest (peak) number of people expected to occupy all *ventilation zones* served by the ventilation system during typical usage.

NOTE: Design system population is always equal to or less than the sum of design zone population for all zones in the area served by the system, since all zones may or may not be simultaneously occupied at design population.

Section 6.2.5.4 Outdoor Air Intake

The design outdoor air intake flow (V_{ot}) shall be determined in accordance with Equation 6-8.

$$V_{ot} = \frac{V_{ou}}{E_v} \tag{6-8}$$

Chapter 4 – Implementing, Troubleshooting and Maintaining a Central DCV System

Chapter 4 describes tasks likely to be carried out on the job site to start a DCV system as the system is started up. The sequence is an example of Combination: Zone CO_2 Sensing with Central Control of Outside Air Intake. It includes information on the following topics:

- Setting up CO_2 sensors
- Setting up building pressurization
- Scheduling purge
- Setting up minimum outside air control
- Setting up controls to meet ASHRAE Standard 62.1-2010 ventilation requirements
- Troubleshooting
- Maintenance

Setting Up CO_2 Sensors

Follow the manufacturer recommendations and make sure that each unit is operating correctly.

Setting Up Building Pressurization

Effective outside air control is impossible without proper building pressurization. When using an open loop pressurization system (it does not use flow stations or building pressure sensors) you must adjust it for acceptable operation throughout the working range. Before adjusting the building pressurization, set up the terminal flow controls and the minimum outside airflow control. Both tasks can be completed with the rough pressurization control. Set up a table in the program and complete the following:

Check and adjust the building pressure at three supply flows: 90%, 60%, and 30% of design flow. Set the supply flow by commanding the terminal flow setpoints.

Check building pressurization and direction of flow at exhaust damper.

- If building pressurization is negative, reduce the return flow at that operating point to make it neutral or positive.
- If building pressurization is *extremely positive*, increase the return flow. Extremely positive means that doors are whistling or standing open, there is a *wind tunnel* in the corridor to an adjoining space, or that measured pressure between inside and outside is about 0.2 inches or more.
- If the exhaust damper draws air in, increase the return flow. The only requirement is that air should move in the right direction at the exhaust damper.

- If it is not possible to get both building pressurization and exhaust flow right, air is being drawn out of the space. Find out where the air is going and try to prevent it, or increase the outside airflow to the building.

Scheduling Purge

Using Time of Day or Equipment Scheduler, schedule the following three points to implement the sequence of modes selected in the design step. If purge is to run immediately before warm-up, cool-down, or the occupied mode, schedule an overlap between DYM and PUR to avoid stopping and restarting the fans.

- **PUR** – Command ON at the time the purge is to begin (assuming purge is at the minimum outside airflow rate). Command OFF at the time the purge is to finish.
- **DYM** – Command ON at the start of warm-up or cool-down. Command OFF at the end of the occupied mode. (If there is no warm-up or cool-down, command ON at the start of the occupied period).
- **OSP** – Command ON at the beginning of the occupied period, command OFF at the end of the occupied period.

Portable sensing devices can be used to measure building generated volatile organic contaminants (VOCs), such as formaldehyde. At a minimum, measurements could be made at the beginning and end of occupancy. The Purge start time should be adjusted early enough so that, with the Minimum Ventilation Rate, VOCs are reduced to an acceptable level at the start of occupancy. The Minimum Ventilation Rate should be increased if the VOC level is too high at the end of occupancy (or any time during occupancy, if additional measurements are made).

Buildings with a high level of VOC generation for example, new construction and materials) may require that Purge be scheduled between warm-up and cool-down and the occupied mode. This will eliminate a buildup of VOCs during the period prior to occupancy, when warm-up/cool-down has the outside and minimum dampers closed.

As an alternative to measuring VOCs, the design engineer can pick an amount of dilution for each purge cycle. The design engineer can pick a volume of outdoor air to be replaced in each purge cycle. The volume of air would be based on replacement of a certain volume of air based on the size of the building or system. The program would then start the purge cycle and measure the amount of volume that is replaced. The purge cycle would end when the volume setpoint is reached. This allows outdoor air intake rates to vary with conditions, but still meet an acceptable purge rate.

Setting up Minimum Outside Air Control

Success of this ventilation control system depends on effectively calibrating the outside airflow. This is a crucial step. The control loop that regulates the pressure in the mixing plenum has to be working before you start. The procedure requires two numbers:

- *Minimum Ventilation Rate* – determined at design time.
- *Design Ventilation Rate* – determined at design time.

The procedure generates the following numbers:

- Plenum pressure that matches the Minimum Ventilation Rate.

- Outside air damper setting that matches the Design Ventilation Rate.

Use the following procedure to set up minimum outside air control:

1. Set the system at a medium supply flow rate by commanding the terminal equipment controllers.
2. Open the minimum outside air damper.
3. Close the modulating outside air damper.
4. Set the mixing plenum pressure setpoint at 0.2 as a starting point.
5. Have the balancer measure outside airflow.
6. Compare the value from the balancer to the desired minimum outside airflow.
7. Adjust the mix pressure setpoint up or down to get the balancer's reading within 5% of the Minimum Ventilation Rate.
8. Record the adjusted value of the mixing plenum pressure setpoint in job documents and in the system.
9. With the mixing pressure controlled, partially open the outside air damper.
10. Adjust the outside air damper setting until the balancer's flow reading is within 5% of Design Ventilation Rate.
11. Record the damper setting on job documents and in the system.

Troubleshooting

Table 4 contains basic troubleshooting information for a central Demand Controlled Ventilation (DCV) system.

Table 4. Troubleshooting a Central DCV System.

Symptom:	What to do:
The CO_2 readings are too high.	If the ventilation system is working correctly, CO_2 concentrations should not exceed the high value in the program that implements DCV. Make sure the minimum outside air damper is open, and the modulating outside air damper opens to the correct position. If the dampers don't open, there won't be enough ventilation. Check the suction pressure in the mixing plenum. If the suction is low, there won't be enough ventilation. Check the actual occupancy of the space. If there are more people than expected, they may need more outside air than the Design Ventilation Rate. Check the activity in the space. If the number of occupants is as expected, but they are more active than anticipated, the CO_2 concentration will go up even at the correct ventilation rate. Consider adjusting the high value of the CO_2 rise, and explain to the owner that the higher level is appropriate. Check the air distribution. If the ventilation rate is right and the occupants are not unusually active, look for air distribution problems in the space.
The CO_2 readings are too low.	Check the control mode of the outside air dampers. If the system is in free cooling mode, that is the explanation. If the space is lightly occupied, a low CO_2 concentration is expected. The proportional control strategy makes the concentration vary with load. Is it a transient? The CO_2 concentration builds slowly when occupants arrive. It can take several hours to reach steady state. If the concentration is still going up, don't look for a problem. If the system is in minimum outside air mode or the DCV mode, check operation of the outside air dampers and the return air dampers. Dampers may be too leaky.

Symptom:	What to do:
The mixing plenum suction is too low.	This may be OK if the outside air damper is open for free cooling, and the return air damper is closed. If this is the case, suction may be low even at high outside airflow. This may be a problem if the return air damper is closed, or if the return air damper is too large and leaky. In this case, even if the damper is closed, too much air re-circulates. You need a tighter shut off in the re-circulating air path. This may be a problem if the return air damper is closed and the supply flow is too low to draw enough outside air. The supply flow is controlled by the terminals, so the AHU must operate so that the supply fan moves enough air to bring in the required outside air.
The mixing plenum pressure cannot be stabilized.	The return fan may be blowing too hard. Check the pressure in the exhaust plenum. If the pressure is less than 0.5 inches, it probably is not a problem. Do not adjust the return fan without checking the building pressurization. The return air damper may be too big. If this is the case, consider blanking off a portion.
The mixing plenum suction is too high.	Make sure the minimum outside air damper is open. Check the return air damper. The pressure control loop should open it to relieve excess suction. If the return air damper is open, check the return fan. You may need to increase return fan flow to relieve pressure. Do not adjust the return fan without considering building pressure.
The building pressure is not within the desired range.	First, recognize that this could be caused by another fan system in the building. This could be a different AHU or a separate exhaust fan. Check for obvious problems with the other fan systems. If the problem is in the unit you are working with, first check the fans. Are they running, not overridden, proof made? Is the VFD tripped or overridden to fixed speed? Are the dampers at the AHU operating correctly? Are the terminal controllers bringing air to the space? If nothing else works, adjust the return fan program table according to the procedure in *Setting Up Building Pressurization* this chapter
Poor IAQ at the beginning of occupancy.	Verify Purge operation prior to occupancy. Check operation of fan and dampers. Look for sources of contaminants and other means to control them. Increase Purge time by scheduling PUR to ON earlier.
Poor IAQ during occupancy, or at the end of occupancy.	Check minimum ventilation control. Determine source of contaminants and reduce or exhaust directly. Increase Minimum Ventilation Rate.

Maintaining a Central DCV System

Maintenance of a central DCV system includes the following tasks:

- Calibrate the CO_2 sensors according to the manufacturer's recommendations.
- Periodically verify the outside air intake at Minimum Ventilation Rate and at Design Ventilation Rate.
- Check and replace filters.
- Verify operation of damper actuators.
- Evaluate air quality. Do this at the start of occupancy, and throughout the day. Evaluate in terms of CO_2 and in other terms.
- Periodically measure building-generated VOCs and adjust purge start and Minimum Ventilation Rate accordingly. As new building materials age, they emit less VOC, so less purge or Minimum Ventilation Rate may be acceptable. Less purge time and minimum ventilation save energy.

It is recommended that a Building Automation System (BAS) be used to track the performance of DCV controlled zones. Measurement and Verification and Continuous Commissioning procedures for DCV zones not only uncover problems early and point to their possible solution, but are very helpful in gaining or maintaining LEED® certification for a building. In addition, some of the Web sites listed in *Role of Ventilation in IAQ* in *Chapter 1* can be helpful for information on general maintenance for IAQ.

Appendix A – Series 2200 Three-in-one Room Unit Technical Data and Features

Technical Data

Temperature Specifications	
Temperature Range	
Operating	55°F to 95°F (13°C to 35°C)
Output Signal	Proprietary digital protocol
Sensing Element Type	Digital Sensor IC
Accuracy	±0.9°F (±0.5°C)
Humidity Specifications	
Humidity Range	0% to 100% rh
Output Signal	Select 0-5V, 0-10V, 4-20 mA
Sensing Element Type	Digital Sensor IC
Humidity Accuracy	
10% - 90% rh	± 2% rh
< 10% rh; > 90% rh	± 4% rh
CO_2 Specifications	
Carbon Dioxide Range (PPM)	0 to 2000 parts per million
Sensing Element Type	Digital Sensor IC
CO_2 Accuracy	+/- 50 PPM + 2% of reading
Calibration Features Temperature Humidity CO_2	 Adjustable to +/- 5°F Adjustable to +/- 5% rh Adjustable to +/- 50 PPM
Installation BACnet PTEC	 100 ft. Maximum cable length. twisted pair NEC Class 2 6C #24 AWG
Installation Adjustments	None required
Cover Dimensions Color	 4.5" × 2.75" × 1.18" (115 mm × 70 mm × 30 mm) White
Regulatory Agencies	UL 916
Power Supply	Supplied by CO_2 Power Module (part number AQM2200)
Product Weight	0.25 lbs.

Features/Functions/Benefits

Features	Functions	Benefits
New footprint (same as the other Series 2200 models for Terminal Equipment Controller (TEC)	Ease of mounting.	Eliminates the need for an adapter plate in order to fit over a 2 x 4 electrical junction box.
Completes the offering in the Series 2200 packaging	Matches the look of the Series 2200 temperature room units for PTEC and field panel.	Provides a uniform appearance for wall mounted devices for primary and zone controllers.
Configurable display parameters*	Customizes display appearance; show/hide display elements.	Suit user/occupant preferences.
Organic Light Emitting Diode (OLED) display	Built-in backlighting.	Display visible in dimly lit spaces.
Digitally communicated measurement values (not available on sensing only models)	A single sensing element reports the same value to both the local room unit display and to the Terminal Equipment Controller.	Consistency of measurement reporting; more accurate measurement; faster updates to controller.
Display of English or SI units	Devices with display may be made to display temperature in either degrees F or C.	No need to specify the correct part number when ordering, as in the Series 1000 models (ex: 544-780FB or 544-780CB).
Display of temperature values to one decimal	Devices with display show temperature values to the tenths of a degree (one decimal place).	Display of more accurate measurement.
Local carbon dioxide (CO_2) adjustment capability (display models only)*	Devices with display allow the displayed and communicated value to be biased to +/- 50 PPM (parts per million) of the CO_2 reading.	Reconciles measurement accuracy to calibrated handheld device.
Local temperature adjustment capability (display models only)*	Devices with display allow the displayed and communicated value to be biased to +/- 5 deg F of the temperature reading.	Reconciles measurement accuracy to calibrated handheld device.
Local humidity adjustment capability (display models only)*	Humidity sensing devices with display allow the displayed and communicated value to be biased to +/- 5% of the humidity reading.	Reconciles measurement accuracy to calibrated handheld device.
Local setpoint limiting (display models only)*	Devices with display can restrict the setpoint adjustment range of 55 to 95°F to any range in between.	Provides means to limit occupant set-point adjustments to extreme temperature values; energy efficient.
Display brightness adjustment capability*	Devices with display can display a relative brightness on a scale of 1 to 10 (10 being brightest).	Optimizes display viewing based on ambient lighting conditions in a variety of environments (classroom, hotel room, etc.).

Features	Functions	Benefits
Removable, replaceable sensing tip (models with RH measurement capability only)	Replaces humidity sensing element if component ever fails.	Service feature; Lowers cost of repair/ replacement.
Graphical or numerical setpoint adjustment* (display models only)	Devices with display can display set-point either as a numerical value or as a relative setting (colder or hotter), based on the setpoint range.	Provides flexibility to customer (or facilities operator preference) on how setpoint information is displayed.
RoHS Compliant	Series 2200 Room Units are lead free and meet the European Unions' Restriction of Hazardous Substances (RoHS) compliance.	RoHS compliant Room Units allow you to meet additional job specifications in your market as the push towards "Green friendly" products and components moves forward.

***NOTES:** Hardware Passkey (part number 544.643A) is needed to change display parameters.

Please see the applicable technical specification sheets and other technical documentation for the complete list of features and functions that are supported.

Glossary

The glossary contains terms and acronyms that are used in this guide.

ASHRAE Standard 62.1

A standard written and maintained by the American Society of Heating, Refrigeration and Air Conditioning Engineers. Title: *Ventilation for Acceptable Indoor Air Quality*. This is one of the primary references on ventilation and IAQ and is approved by the American National Standards Institute.

ASHRAE Standard 90.1

A standard written and maintained by the American Society of Heating, Refrigeration and Air Conditioning Engineers. Title: *Energy Standard for Buildings Except Low-Rise Residential Buildings*. This is ASHRAE's primary energy standard for commercial and institutional buildings.

Building Pressurization

The balance between mechanically driven airflows into and out of a building. Affects infiltration, drafts at openings in the building, and operation of doors.

Carbon Dioxide

A colorless, odorless, gas formed especially in animal respiration.

CO_2 Based DCV

A system of Demand Controlled Ventilation, in which the need for ventilation is determined by measurements of CO_2 concentration in the occupied spaces or in the return air.

DCV

Demand Control Ventilation

Demand Controlled Ventilation (DCV)

A ventilation control system in which the outside airflow rate is dynamically adjusted according to the varying occupancy of the space. A DCV system is a typical energy conservation strategy and is most effective for large spaces with variable occupancy, such as lecture halls, auditoriums, gymnasiums. However, it can also be applied to smaller zones such as conference rooms, meeting rooms and class rooms (college or adult only – do NOT attempt to implement DCV for K – 12 schools since ASHRAE Standard 62.1 applies to body mass and met levels for adults only).

Design Ventilation Rate

The outside airflow rate needed for a space at "design occupancy." This value depends on the type of space and the design requirements.

IAQ

Indoor Air Quality.

IMC

International Mechanical Code. A model building code document from the International Code Council.

Met Level

A unit of human metabolic activity level which is proportional to the rate of oxygen consumption and/or CO_2 generation.

Purge

A control scheme designed to rapidly reduce the level of contaminants that affect IAQ in a building. As part of this DCV control, purge is intended to reduce VOC levels prior to building occupancy. (Referred to as Lead Ventilation in the BSR/ASHRAE 62-1989R, Public Review Draft).

PTEC

Programmable Terminal Equipment Controller.

R_a

The building component of the minimum ventilation rate at zero occupancy to remove the effluents from the space (due to off gassing of the carpets, wood paneling, furnishings, etc. in the building space).

Ventilation

The process of supplying and removing air, by natural or mechanical means, to and from any space. Such air may or may not be conditioned.

Ventilation Air

The portion of supply air that is outdoor air plus any recirculated air that has been treated for the purpose of maintaining acceptable indoor air quality.

VFD

Variable Frequency Drive.

VOCs

Volatile Organic Contaminants. These are building generated contaminants that affect IAQ independent of occupancy levels.

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Program for a Demand Controlled Ventilation (DCV) System Program for a Demand Controlled Ventilation (DCV) System

Program for a Demand Controlled Ventilation (DCV) System Program for a Demand Controlled Ventilation (DCV) System